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ASTRONOMICAL OBSERVATIONS.

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ASTRONOMICAL OBSERVATIONS

MADE IN

ST. JOHN'S COLLEGE, CAMBRIDGE,

IN THE

YEARS 1767 AND 1768:

WITH AN ACCOUNT OF

SEVERAL ASTRONOMICAL INSTRUMENTS,

By the Reverend Mr. LUDLAM.

CAMBRIDGE,

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P R E F A C E.

THE Observatory at St. *John's* College in *Cambridge*, where the following observations were made, was built at the expense of the same person who gave to that society the astronomical instruments used in making them; a Gentleman, who to his exquisite taste and skill in polite literature adds a profound knowledge of Philosophy, and has a disposition and a heart to promote them both: and, which is still more beneficial to the world, and equally honourable to himself, he joins to a consummate excellence in his profession, a generosity without limits in the exercise of it.

The observations were made with care, and the facts are faithfully related, nor are any circumstances falsified or suppressed to give them a credit to which they have no title.

To the observations is subjoined a particular account of the instruments, the methods taken to rectify them, the determination of the latitude and longitude of the place, and other circumstances proper to be ascertained at the fitting up of a new observatory; all which may be of service to others on the like occasion: an account of what has been actually done is perhaps more useful than any precepts whatever.

After the account of the instruments in the observatory, there follows a description of some others; not imaginary ones, but such as have been really made. It is too common a fault in the writers on practical mechanics, instead of realities to give us reveries which never did and perhaps never could exist. In many instruments there is required a particular size and proportion of the parts, which yet can be known only by experience; sometimes the merit of an instrument arises from some peculiar way of making it, in which the parts can be formed with ease, or put together with accuracy; the whole process must then be related, as well as the size of the parts noted down: it is hoped this may

*

apologize

apologize for the long account of the tranfit instrument made of tin, and the pendulum with a wooden rod.

The properties of *Hadley's* quadrant were demonstrated by the inventor, in a manner different from that which I have made use of. He has likewise given a method of correcting the errors that arise from not holding the instrument precisely in the plane of the objects observed; but as it is almost as easy to hold the quadrant exactly in that plane as nearly so, and the error itself is but small, this correction is now generally neglected in practice. The errors arising from the nearness of the objects are in some topographical cases considerable, and therefore the rules for finding them are here laid down.

The optical paper is intended to give some idea of the advantages proposed in making telescopes with several eye-glasses, as is the present practice. The principles upon which their magnifying power may be computed are likewise explained, without those complicated algebraic expressions, which can never assist the reader in conceiving rightly of the progress of the rays after their several refractions and reflections. It were to be wished that writers on this subject would draw their figures from real instruments; instead of which their schemes are often utterly inconsistent with all the rules of optics, and therefore tend rather to confound than assist the imagination of the reader.

The paper which follows is only the application of the common rules of spherical trigonometry to some useful problems in practical astronomy.

Part of one of the problems relating to pendulums is in *Huygens*; but the case he particularly considers is not applicable to compound pendulums such as are generally now made, nor does he extend his enquiry to some necessary circumstances which that case requires.

The subject of clock and watch-work would furnish problems enough to fill a volume; what are here proposed are merely elementary,

P R E F A C E.

elementary, yet they are not to be found in any of the writers on this subject: a much shorter solution of the first of these might have been given, but not founded on principles so well established as the *Newtonian* doctrine of the composition and resolution of forces.

I cannot conclude without acknowledging my obligations to *Mr. Dunthorne*. To those who have looked deep into these subjects it is enough to have given his name. Others may please to be informed that there is a person at *Cambridge* who, without the benefit of an Academical education, is arrived at such a perfection in many branches of learning, and particularly in Astronomy, as would do honour to the proudest Professor in any University: and yet, notwithstanding this supreme skill in a science so difficult and so important, Humanity and Modesty, the most engaging diffidence of himself, and readiness to advance others, are parts of his character not only more excellent and amiable, but more peculiar and distinguishing.

CAMBRIDGE,
Jan. 10, 1769.

E R R A T A.

page 12, *for* Gemini *read* Geminorum.

page 44, *against* Jan. 16 day, VII^h 41' 27" in the thermometer without, *for* 48 *read* 38.

page 44, paragraph 12, line 9. *should be read thus*, the points in which that circle intersects the meridian and horizon, and its inclination to each of them may be found, if the passage of the sun or any known star both over that circle and over the meridian be given; the former of which may be observed directly in the transit telescope, and the latter may be inferred from corresponding altitudes.

page 99, line 21, *after* meet *add* the axis.

At the bottom of page 117 *add the following note*,

Hence $e = \frac{d}{2l} \pm \frac{1 \times 3 d^2}{2 \times 4 l^2} + \frac{1 \times 3 \times 5 d^3}{2 \times 4 \times 6 l^3} \pm \frac{1 \times 3 \times 5 \times 7 d^4}{2 \times 4 \times 6 \times 8 l^4} \&c.$ $\times t$ if the pendulum be shortened
lengthened.

A D V E R T I S E M E N T.

THE titles at the head of each column in the following pages are sufficient to explain their contents. In the column of transits, that of the sun takes up two lines; the first is the passage of the western, the second that of the eastern limb over the wires. + or — added, signifies somewhat more or less, not amounting to half a second. Two lines likewise belong to the sun in the column of zenith distances, the first is the zenith distance of the lower, the second that of the upper limb; when only one of these distances was taken, it is marked U. L. or L. L. for upper or lower limb.

There are two sets of divisions on the quadrant, one into degrees and minutes; the other into 96 parts, each part into 8 subdivisions, and each of these into 16 by the Nonius or Vernier. The zenith distance shown on each scale is given in the 6th and 7th columns. In these (a) denotes an observation to be very good; (d) doubtful; (c) a perfect coincidence of the strokes on the limb and Vernier; + or — a little more or less, but not so much as to separate the strokes; when they were intirely separated, the part of one division to be allowed on that account was estimated by the eye, and is set down fraction-wise. E or W denotes that the face of the quadrant was to the east or to the west in observations made for finding the error of the line of collimation: All other meridian zenith distances were taken on the quadrantal arch; the face of the instrument looking towards the east, if the star passed the southern part of the meridian; towards the west, if it passed the northern part.

Both thermometers are made by *Fahrenheit's* scale.

O B S E R-

ASTRONOMICAL OBSERVATIONS.

Day of the Month 1767.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
July 9	2 39 4 56	0 4 8 6 25	5 36 7 53	} Sun					
10	9 9	x 10 33	11 57	α Ophiuci					
11	2 58 $\frac{1}{2}$ 5 54 46 36 40 8 5 24	0 4 26 $\frac{1}{2}$ 6 43 VI 48 3 $\frac{1}{2}$ IX 42 4 x 7 39 6 37 14 26 $\frac{1}{2}$ 18 41 33 36 XI 11 21 $\frac{1}{2}$ XXI 40 5	5 15 8 11 49 30 $\frac{1}{2}$ 44 2 9 52 15 48 20 1 $\frac{1}{2}$ 35 47 13 6 42 1 $\frac{1}{2}$	} Sun Arcturus Capella β Draconis α Ophiuci β Ophiuci γ Ophiuci γ Draconis Lyra Capella	81 57 0 16	87 3 5 0 2 4 W	29,6	60	
12	3 7 $\frac{1}{2}$ 5 25 52 25 36 12 $\frac{1}{2}$ 1 18 9 9 $\frac{1}{2}$ 13 24	0 4 35 $\frac{1}{2}$ 6 53 VIII 53 56 IX 38 9 x 2 42 10 32 14 46	6 3 $\frac{1}{2}$ 8 20 55 26 $\frac{1}{2}$ 40 6 $\frac{1}{2}$ 4 5 11 53 16 7	} Sun Antares Capella α Ophiuci β Ophiuci γ Ophiuci					
14	34 50 $\frac{1}{2}$	VI 36 18	37 45	Arcturus					
15	57 23 $\frac{1}{2}$ 15 43	IX 58 46 x 3 0 17 55	0 8 4 22 20 6	β Ophiuci γ Ophiuci γ Draconis	0 40 $\frac{1}{2}$	0 5 12 E			
16	36 44 20 32 53 28 $\frac{1}{2}$ 57 43 11 48 56 20 0 33 $\frac{1}{2}$ 5 1	VIII 38 15 IX 22 28 54 51 59 5 x 14 0 XI 57 43 XII 1 56 6 23	39 46 24 26 56 12 0 26 16 10 59 6 3 18 7 45	Antares Capella β Ophiuci γ Ophiuci γ Draconis γ Aquilæ α Aquilæ β Aquilæ					
18	12 41 37 46 45 38	IX 14 38 39 10 $\frac{1}{2}$ 47 0 51 14	16 35 40 33 $\frac{1}{2}$ 42 21	Capella α Ophiuci β Ophiuci γ Ophiuci					
19	15 14 8 47 33 51 $\frac{1}{2}$	VI 16 41 $\frac{1}{2}$ IX 10 42 35 15	18 8 12 40 ^d	Arcturus Capella α Ophiuci					
23	6 26 51 5 $\frac{1}{2}$	0 5 38 7 53 IX 46 34 XX 53 3	7 5 9 19 $\frac{1}{2}$ 48 44 55 0	} Sun γ Draconis Capella					
24	4 15 6 29 55 38 49 10 14 15	0 5 42 v 57 6 VIII 51 7 IX 15 39	59 32 $\frac{1}{2}$ 8 23 $\frac{1}{2}$ 17 2 $\frac{1}{2}$	} Sun Arcturus Antares Capella α Ophiuci					

Day of the Month 1767.	Time by the Clock.				Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.		Third Wire.		Deg.	Parts of 96			
July 24	22 6 $\frac{1}{2}$	IX	23 28	24 50	β Ophiuci					
	26 21		27 42	29 4	γ Ophiuci					
	18 39	X		22 7 $\frac{1}{2}$	Lyra					
	11 0	XI	12 32	14 3	β Cygni					
	29 12		30 34 $\frac{1}{2}$	31 57	α Aquilæ	43 55	46 6 12 a			
	25 4 17	O	5 44	7 10	} Sun					
	6 31		7 58	9 25						
	26 41 20 $\frac{1}{2}$	VII	59 3	0 34	Antares					
		VIII	43 17	45 14	Capella					
	14 17	IX	15 19	17 0	β Draconis	0 17	0 2 7 $\frac{1}{4}$ Ea			
	32 37		34 49	36 59	β Ophiuci					
	10 49	X		14 16 $\frac{1}{2}$	γ Draconis	0 40 $\frac{1}{2}$	0 5 11 $\frac{3}{4}$ E			
	39 20	XX	41 18	43 14	Lyra	13 37	14 4 3			
					Capella					
	31 6 33	O	5 44	7 11	} Sun					
			7 57 $\frac{1}{2}$	9 23						
Aug. 1	4 16	O	5 42		} Sun					
	6 29		7 55	9 21						
	24 18	V	25 46	27 12	Arcturus					
		VII	35 33	37 3	Antares					
	17 51	VIII	19 47	21 45	Capella	81 56 $\frac{3}{4}$	87 3 5 —	31.45	64	
	50 56		52 8 $\frac{1}{2}$	53 30	β Ophiuci					
	55 2 $\frac{1}{2}$		56 23	57 44	γ Ophiuci					
	9 6	IX	11 18	13 28	γ Draconis	0 40 $\frac{1}{4}$	0 5 11 $\frac{1}{4}$ Ea			
	15 20	XX	17 48	19 44	Capella					
	2 4 13 $\frac{1}{2}$	O	5 39 $\frac{1}{2}$	7 5 $\frac{1}{2}$	} Sun U.limb					
				9 18 $\frac{1}{2}$						
	20 22	V	21 50	23 17	Arcturus	34 7 $\frac{1}{2}$	36 3 3			
	30 7	VII	31 38	33 9	Antares					
	13 55	VIII	15 51	17 49	Capella					
	51 4		52 26	53 47 $\frac{1}{2}$	γ Ophiuci					
	5 11	IX	7 23	9 33	γ Draconis	0 40	0 5 11 E			
		XX	13 52	15 48	Capella					
	3 4 9 $\frac{1}{2}$	O	5 36	7 1	} Sun					
	6 23		7 49 $\frac{1}{4}$	9 14 $\frac{1}{2}$						
	16 27	V	17 55	19 21	Arcturus	31 47 $\frac{1}{2}$	33 7 4 $\frac{1}{2}$			
		VII	27 42	29 14	Antares					
	10 0	VIII	11 56 $\frac{1}{2}$	13 54	Capella					
	42 56 $\frac{1}{2}$		44 19		β Ophiuci					
	1 15	IX	3 27 $\frac{1}{2}$	5 38	γ Draconis					
	39 28		41 13	42 57	Lyra					
	4 6 18	O	5 31 $\frac{1}{4}$	6 57	} Sun					
			7 44 $\frac{1}{4}$							
	12 32	V	13 59 $\frac{1}{2}$	15 25 $\frac{1}{2}$	Arcturus					
	6 4	VIII	8 1	9 59	Capella					
	31 9		32 33 $\frac{1}{2}$	33 56 $\frac{1}{2}$	α Ophiuci					
	39 0 $\frac{1}{2}$		40 23	41 44	β Ophiuci					
	43 15 $\frac{1}{4}$		44 37	45 58	γ Ophiuci					
	57 20		59 32	1 42	γ Draconis					
	16 12	IX	17 34 $\frac{1}{2}$	18 56	γ Ophiuci					
	35 32 $\frac{1}{2}$		37 17	39 1	Lyra					
	5 4 1	O	5 27	6 51	} Sun					
	6 14		7 40 $\frac{1}{2}$	9 4						

Day of the Month 1767.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Aug. 6	3 56 6 9 4 41 $\frac{1}{2}$	o 5 22 $\frac{1}{4}$ v 7 34 $\frac{1}{4}$ 6 9	6 47 $\frac{1}{4}$ 9 0 $\frac{1}{2}$ 7 36	} Sun Arcturus					
8	19 52	IX 21 37 $\frac{1}{2}$	23 21	Lyra					
10	3 29 5 42 7 38 $\frac{1}{2}$	o 4 54 7 7 VIII 9 2 $\frac{1}{2}$	6 18 8 31 10 25 $\frac{1}{2}$	} Sun α Ophiuci					
11	8 6	IX 9 51 $\frac{1}{2}$	11 35 $\frac{1}{2}$	Lyra					
12	3 13 $\frac{1}{2}$ 5 25 41 11 32 44	o 4 38 $\frac{1}{2}$ 6 50 IV 42 38 $\frac{1}{2}$ XIX 34 41	6 2 $\frac{1}{2}$ 8 14 $\frac{1}{2}$ 44 5 36 38	} Sun Arcturus Capella					
14	24 54	XIX 26 51	28 47	Capella					
15	2 44 48 1 $\frac{1}{2}$ 55 54 14 14 $\frac{1}{4}$ 52 26 2 59	o 4 9 VII 24 54 49 26 $\frac{1}{2}$ 57 16 VIII 16 25 $\frac{1}{4}$ 54 11 x 4 22	26 53 50 49 $\frac{3}{4}$ 58 37 $\frac{1}{4}$ 18 35 $\frac{3}{4}$ 55 55 5 44	} Sun Capella α Ophiuci β Ophiuci γ Draconis Lyra α Aquilæ	13 36 $\frac{3}{4}$	14 4 2 +		66	
16	44 7 $\frac{1}{4}$ 51 58 $\frac{1}{2}$ 10 18 $\frac{1}{4}$ 48 30 $\frac{1}{2}$	VII 45 31 $\frac{1}{2}$ 53 21 VIII 12 30 50 15 $\frac{1}{2}$	46 54 $\frac{1}{2}$ 54 42 $\frac{1}{4}$ 14 40 $\frac{1}{4}$ 51 59 $\frac{1}{2}$	α Ophiuci β Ophiuci γ Draconis Lyra	13 36 $\frac{1}{2}$	14 4 2 —			
17	4 32 $\frac{3}{4}$	o 3 46 $\frac{1}{2}$ 5 58 $\frac{1}{4}$ VII 15 6 $\frac{3}{4}$	5 10 7 21 17 2 $\frac{1}{4}$	} Sun L. limb U. limb Capella	39 0 38 28	41 4 12 $\frac{1}{2}$ 41 0 3 $\frac{1}{2}$		66	
18	2 10 4 21 40 40	o 3 35 5 46 VII 37 41 $\frac{1}{2}$ VIII 42 25 $\frac{1}{4}$	4 59 7 9 39 4 $\frac{1}{2}$ 44 9 $\frac{1}{4}$	} Sun α Ophiuci Lyra	38 47 $\frac{4}{10}$ 13 36 $\frac{3}{4}$	41 7 8 $\frac{1}{2}$ 41 3 0 14 4 2 $\frac{1}{2}$		66	
19	1 58 4 9 13 44 $\frac{1}{2}$	o 3 23 5 33 IV 15 12	4 46 $\frac{1}{2}$ 6 56 $\frac{1}{2}$ 16 38 $\frac{1}{2}$	} Sun Arcturus	39 39 39 6 $\frac{3}{4}$	42 2 5 $\frac{1}{2}$ 41 6 12 —		66	
20	54 38	VII 56 49 $\frac{1}{4}$	59 0 $\frac{1}{4}$	γ Draconis				65	
21	28 55 50 50 $\frac{1}{4}$ 56 1 21 16 $\frac{1}{2}$ 35 14 39 28 $\frac{1}{2}$	VII 1 25 VIII 30 39 $\frac{3}{4}$ 45 26 $\frac{1}{2}$ 52 19 57 29 IX 22 49 36 39 40 51 $\frac{1}{4}$ 45 18 $\frac{1}{4}$	3 23 32 23 $\frac{1}{4}$ 46 54 53 46 58 56 24 20 $\frac{1}{4}$ 38 1 42 13 $\frac{1}{4}$ 46 40	Capella Lyra ξ Sagittarii σ Sagittarii π Sagittarii β Cygni γ Aquilæ α Aquilæ β Aquilæ	74 12 $\frac{3}{4}$ 73 31 $\frac{1}{3}$ 24 42 $\frac{1}{2}$ 43 55	79 1 4 $\frac{1}{2}$ 78 3 7 + 26 2 13 — 46 6 12 c		63 $\frac{1}{4}$	

Day of the Month 1767.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Aug. 24	38 57	VII 41 9	43 18	γ Draconis					
25	0 35 $\frac{1}{2}$ 2 46	0 2 0	3 21	} Sun L.L.	41 40	44 3 8 $\frac{1}{2}$		65	
	50 10 $\frac{1}{2}$	III 51 40 $\frac{1}{2}$	52 8 $\frac{1}{2}$	Arcturus					
	8 51 $\frac{1}{4}$	VII 10 15 $\frac{1}{2}$	11 38 $\frac{1}{2}$	α Ophiuci					
	16 41 $\frac{3}{4}$	18 5	19 26 $\frac{1}{2}$	β Ophiuci					
	20 57	22 19	23 40 $\frac{1}{2}$	γ Ophiuci					
	35 2	37 14	39 24	γ Draconis					
	13 15	VIII 16 43 $\frac{3}{4}$	16 43 $\frac{3}{4}$	Lyra	13 36 $\frac{3}{4}$	14 4 2 $\frac{1}{3}$			
		29 46	31 13 $\frac{1}{2}$	ξ Sagittarii					
	35 9 $\frac{1}{2}$	36 38 $\frac{1}{2}$	38 5 $\frac{1}{2}$	$\circ$ Sagittarii					
	40 20	41 48 $\frac{3}{4}$	43 16	π Sagittarii	73 31 $\frac{1}{4}$	78 3 6 $\frac{1}{2}$			
	5 36	IX 7 9	8 40	β Cygni	24 42 $\frac{1}{4}$	26 3 12			
	19 35	20 58	22 20 $\frac{1}{2}$	γ Aquilæ					
	28 15 $\frac{1}{2}$	29 38	31 0	β Aquilæ					
26	39 53	VI 41 50	43 47	Capella				66	
	4 56 $\frac{1}{2}$	VII 6 20 $\frac{1}{4}$	7 43 $\frac{1}{4}$	α Ophiuci					
	31 7	33 19	35 29	γ Draconis					
	9 20	VIII 11 4	12 48 $\frac{3}{4}$	Lyra					
27	42 23	III 43 51	45 18	Arcturus					
	35 58	VI 37 54 $\frac{1}{4}$	39 52	Capella					
	1 1 $\frac{1}{2}$	VII 2 24 $\frac{1}{4}$	3 48	α Ophiuci					
	5 24	VIII 7 9	8 53	Lyra	43 36 $\frac{1}{3}$	44 4 2 a			
		XVIII 35 54 $\frac{1}{2}$	37 51	Capella					
28	38 28	III 39 55	41 22 $\frac{1}{4}$	Arcturus				69 $\frac{3}{4}$	
	32 3	VI 33 59	35 57	Capella					
		58 29 $\frac{1}{2}$	59 52 $\frac{1}{2}$	α Ophiuci					
	30 1 $\frac{1}{2}$	XVIII 31 59	33 55 $\frac{1}{4}$	Capella					
29	59 32	0 0 55	2 18	} Sun	43 4 $\frac{1}{4}$	45 7 8+a		70	
		3 4	4 26		42 32 $\frac{1}{2}$	45 3 0 c			
	34 33	III 36 0 $\frac{1}{2}$	37 27	Arcturus					
	28 8	VI 30 3 $\frac{3}{4}$	32 1 $\frac{3}{4}$	Capella					
	53 10	54 34	55 58	α Ophiuci					
Septem. 1	58 40 $\frac{3}{4}$ 0 49	0 0 3 $\frac{1}{4}$ 2 12	1 25 $\frac{1}{2}$ 3 34	} Sun				67 $\frac{1}{2}$	
3	57 46	XXIII 59 9	0 31	} Sun				67	
4	59 54 $\frac{1}{2}$	0 1 17 $\frac{1}{2}$	2 39						
5	36 28	VIII 37 51 $\frac{1}{2}$	39 13 $\frac{1}{2}$	γ Aquilæ					
	40 41 $\frac{1}{2}$	42 4 $\frac{1}{2}$	43 26 $\frac{1}{2}$	α Aquilæ					
	45 8	46 30 $\frac{1}{2}$	47 51 $\frac{1}{2}$	β Aquilæ					
9	6 48 $\frac{1}{4}$	VIII 8 21	9 52 $\frac{1}{4}$	β Cygni					
	20 47 $\frac{1}{4}$	22 11	23 33	γ Aquilæ					
	25 1	26 24	27 46	α Aquilæ					
	29 28	30 50	32 12	β Aquilæ					
	55 50	XXIII 57 13	58 35	} Sun	47 30 $\frac{1}{2}$	50 5 6 $\frac{1}{2}$		62	
	58 0	59 23	0 44		46 57				
10	16 52 $\frac{1}{4}$ 21 6	VIII 18 15 $\frac{1}{2}$ 22 29	19 37 $\frac{3}{4}$ 23 51	γ Aquilæ α Aquilæ					

Day of the Month 1767.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Sept. 10	25 33 14 29	VIII 26 55 IX 16 24 $\frac{1}{4}$	28 17 18 18	β Aquilæ α Cygni					
11	12 57 $\frac{1}{4}$ 17 11 55 11 57 19 $\frac{3}{4}$	VIII 14 20 $\frac{1}{2}$ 18 34 XXIII 56 34 58 42	15 43 19 56 57 55 0 3 $\frac{1}{2}$	γ Aquilæ α Aquilæ } Sun					
12	54 51 $\frac{1}{2}$	XXIII 56 14 $\frac{1}{2}$	59 44	} Sun					
17	53 10 55 18	XXIII 54 33 56 40 $\frac{1}{2}$	55 54 58 2	} Sun				67	
20	52 10 54 19	XXIII 53 33 55 42	54 54 57 2	} Sun				67 $\frac{3}{4}$	
21	46 $\frac{1}{2}$ 37 59 $\frac{1}{2}$ 51 51 53 59	VII 21 18 $\frac{1}{2}$ 39 22 43 48 $\frac{1}{2}$ XXIII 53 13 55 21	22 50 40 43 $\frac{1}{2}$ 45 10 54 33 $\frac{1}{2}$ 56 42	β Cygni α Aquilæ β Aquilæ } Sun	43 55 52 8 51 35 $\frac{1}{2}$	46 6 12 c 55 4 14 55 0 5	30,42 30,245	63 66	63
22	27 26 $\frac{1}{4}$ 51 30 $\frac{3}{4}$ 53 39	VIII 29 21 XXIII 52 53 55 1 $\frac{1}{4}$	31 14 $\frac{1}{2}$ 54 13 56 23	α Cygni } Sun	52 31 $\frac{1}{3}$ 51 59	56 0 3 $\frac{1}{2}$ 3 9 $\frac{1}{2}$	30,85	65 $\frac{1}{2}$	61
23	19 34 $\frac{1}{4}$	VI 21 19	23 3	Lyra					
24	15 39	VI 17 24	19 8	Lyra	13 36 $\frac{1}{2}$	14 4 2			
25	11 44	VI 13 29	15 12 $\frac{1}{4}$	Lyra					
27	49 54 52 2 $\frac{1}{2}$	XXIII 51 17 53 24 $\frac{1}{4}$	52 37 54 46	} Sun	54 28 $\frac{1}{2}$ 53 56 $\frac{1}{2}$	57 8 14 57 4 5		64	
29	56 4 0 1	V 57 49 $\frac{1}{2}$ VIII 1 55 $\frac{3}{4}$	59 33 3 49 $\frac{1}{4}$	Lyra α Cygni					
*	12 57 51 25 $\frac{1}{2}$	XII 13 41 XXIII 50 39 $\frac{1}{2}$ 52 48	14 25 52 0 $\frac{1}{2}$ 54 9	Polaris } Sun	35 50 $\frac{1}{2}$	38 1 13 $\frac{1}{4}$		60	
30	51 7 $\frac{1}{2}$	XXIII 50 21 52 29	51 42 $\frac{1}{2}$ 53 51	} Sun				59	
October 3	50 15	XXIII 51 37	50 50 52 58 $\frac{1}{2}$	} Sun	56 48 $\frac{3}{4}$ 56 16 $\frac{1}{4}$	60 4 13 c 60 0 3 $\frac{1}{2}$		55	
4	51 30 17 15 53 20 47 48 49 58	VI 48 25 52 52 VII 42 13 $\frac{1}{2}$ IX 18 40 XI 49 10 $\frac{1}{2}$	49 48 54 13 44 13 20 5 54 40 52 42	α Aquilæ β Aquilæ α Cygni D 1st limb Polaris } Sun					
5	49 10	XI 49 57	50 55	Polaris					
6	47 14 49 25	XXIII 48 38 50 47	49 59 $\frac{1}{2}$	} Sun				61	59 $\frac{1}{2}$

* In the pole star, the appulse to, bisection, and leaving of the center wire are taken, not the passage over all the wires.

Day of the Month 1767.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
October 8		XXIII 48 6 50 16	49 28 51 37 $\frac{1}{2}$	} Sun U. L.	58 11 $\frac{1}{4}$	62 0 9 —		53	47
9	53 53 16 51 $\frac{3}{4}$ 9 14 23 13 27 27 31 54 $\frac{1}{4}$ 32 6 $\frac{1}{2}$	O 55 20 V 18 37 VI 10 16 $\frac{3}{4}$ 24 36 $\frac{1}{2}$ 33 16 $\frac{1}{2}$ IX 33 41 $\frac{1}{2}$ 42 4 $\frac{1}{4}$ XI 34 14 XXIII 47 50 $\frac{1}{2}$ 50 0 $\frac{1}{2}$	56 47 20 21 12 18 25 59 30 11 $\frac{1}{2}$ 34 38 35 16 $\frac{1}{4}$ 43 28 49 12 $\frac{1}{2}$ 51 23	Arcturus Lyra β Cygni γ Aquilæ α Aquilæ β Aquilæ Fomalhaut α Pegasi Polaris } Sun	13 36 $\frac{1}{2}$ 43 54 $\frac{1}{2}$ 82 55 38 13 $\frac{1}{4}$	14 4 2 c 46 6 11 88 3 10 c 40 6 2 c		51	44
10	50 57 $\frac{1}{2}$ 12 56 $\frac{1}{2}$ 46 13 48 23	O 51 25 V 14 41 $\frac{1}{2}$ XXIII 47 36 49 46 $\frac{1}{2}$	52 56 $\frac{1}{2}$ 16 26 48 58 51 8	Arcturus Lyra } Sun				52	48
11	45 58 $\frac{1}{2}$	XXIII 47 21 $\frac{1}{2}$	50 53	} Sun				52 $\frac{1}{2}$	46
12	47 54	47 7 $\frac{1}{4}$ 49 17	48 29 $\frac{1}{4}$ 50 39	} Sun				54	47
13	47 41	XXIII 49 4	48 16	} Sun				56	49 $\frac{3}{4}$
14	45 18 47 29	XXIII 46 41 $\frac{1}{2}$ 48 52	48 3 50 14	} Sun				55 $\frac{1}{2}$	48
16	49 23 52 1 4 37 $\frac{1}{2}$ 5 50 47 5	IV 51 8 VIII 53 34 IX 6 13 XI 6 35 XXIII 46 17 $\frac{1}{2}$	52 52 55 7 $\frac{1}{2}$ 7 47 $\frac{1}{2}$ 7 5 49 50 $\frac{1}{4}$	Lyra γ Pegasi Fomalhaut Polaris } Sun	35 50 $\frac{2}{3}$	38 1 13 +		58 $\frac{1}{2}$	50
18	44 32 $\frac{1}{2}$ 46 43 $\frac{1}{4}$	XXIII 45 56 48 6 $\frac{3}{4}$	47 18 49 29	} Sun				56 $\frac{1}{2}$	51 $\frac{1}{4}$
23	25 52 $\frac{1}{2}$ 46 2 $\frac{1}{4}$	VI 27 47 XXIII 45 14 $\frac{1}{2}$ 47 26 $\frac{1}{2}$	29 40 46 37 $\frac{1}{2}$ 48 49	α Cygni } Sun	64 14 63 41 $\frac{1}{2}$	68 4 2 67 7 8		63	59
24	18 0 10 22 24 21 28 35 21 56 $\frac{1}{4}$	IV 19 45 V 11 54 $\frac{1}{4}$ 25 45 29 58 34 25 VI 23 51 $\frac{1}{2}$	21 29 13 25 $\frac{3}{4}$ 27 8 31 20 35 46 25 45 $\frac{3}{4}$	Lyra β Cygni γ Aquilæ α Aquilæ β Aquilæ α Cygni	13 36 $\frac{3}{4}$ 24 42 43 55 7 44—	14 4 2 $\frac{1}{2}$ 26 2 12 46 6 12 $\frac{1}{2}$ 8 1 15 c			
26	43 34 45 46	XXIII 44 58 $\frac{1}{2}$ 47 11	46 21	} Sun				63 $\frac{1}{2}$	57
27	6 15	IV 8 0 V 18 12 $\frac{1}{2}$ 22 39	9 43 $\frac{1}{2}$	Lyra α Aquilæ β Aquilæ					

Day of the Month 1767.	Time by the Clock.				Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.		Third Wire.		Deg.	Parts of 96			
Oct. 29	43 34	XXIII	44 48 $\frac{1}{2}$	46 12 48 25 $\frac{1}{2}$	} Sun				63	61
30	45 35 $\frac{1}{2}$	XXIII	44 47 0 $\frac{1}{2}$	46 11 48 24 $\frac{1}{2}$	} Sun				57 $\frac{1}{2}$	53 $\frac{1}{2}$
31		V	2 32 58 $\frac{1}{2}$		α Aquilæ β Aquilæ α Cygni	7 43 $\frac{2}{3}$	8 1 15			
	54 31 43 22 45 35	XXIII	44 45 $\frac{1}{2}$ 46 59	58 20 46 9 $\frac{1}{2}$ 48 23	} Sun					
Nov. 2	43 21	XXIII	44 47 1	46 11 48 25	} Sun	67 33 67 0 $\frac{1}{4}$	72 0 7 $\frac{1}{4}$ 71 3 12 $\frac{1}{2}$		63	58
3	43 24 45 37 $\frac{1}{2}$	XXIII	44 48 2 $\frac{1}{2}$	46 12 $\frac{1}{2}$ 48 27 $\frac{1}{2}$	} Sun				59	51 $\frac{1}{2}$
6	43 32 45 47	XXIII	44 57 $\frac{1}{2}$ 47 12	46 22 $\frac{1}{2}$ 48 37 $\frac{1}{2}$	} Sun				57 $\frac{3}{4}$	55
7	59 29 $\frac{1}{2}$ 7 55 15 27	XIII	1 54 9 21 $\frac{1}{2}$ 16 52	2 18 10 47 18 17	γ Tauri ϵ Tauri Aldebaran					
8	43 41 $\frac{1}{2}$ 45 58 $\frac{1}{2}$	XXIII	45 9 47 24 $\frac{1}{2}$	46 33 48 49	} Sun				59	57
12	44 14 46 30 $\frac{1}{2}$	XXIII	45 40 $\frac{1}{2}$ 47 55 $\frac{1}{2}$	47 5 $\frac{1}{2}$ 49 22	} Sun					
13		VII	19 20 20 52	21 54 23 53	β Urfæ majoris α Urfæ majoris					
	14 44 $\frac{1}{2}$ 15 47 44 24 46 40 $\frac{1}{2}$	XIX XXIII	18 49 $\frac{1}{2}$ 45 50 48 6 $\frac{1}{2}$	21 48 47 16 49 32	β Urfæ majoris α Urfæ majoris } Sun					
14	55 43 6 18 13 4 $\frac{1}{2}$ 13 59 8 39 $\frac{1}{4}$ 40 30 48 1 46 52	II IV VII IX XII XXIII	57 27 $\frac{1}{2}$ 7 41 15 26 16 57 13 5 11 10 33 29 41 56 $\frac{1}{2}$ 49 27 $\frac{1}{2}$ 46 1 $\frac{1}{2}$ 48 19	59 11 $\frac{3}{4}$ 9 2 $\frac{1}{2}$ 17 59 19 58 34 53 43 22 50 52 47 26 $\frac{1}{2}$ 49 44 $\frac{1}{2}$	Lyra α Aquilæ β Urfæ majoris α Urfæ majoris Polaris ϵ Urfæ majoris γ Tauri ϵ Tauri Aldebaran } Sun	64 45 $\frac{3}{4}$	69 0 10 $\frac{1}{2}$		52	47
15	51 48 9 0 10 4 $\frac{1}{2}$	II VII	53 32 $\frac{1}{2}$ 11 31 13 3	55 16 $\frac{1}{2}$ 14 4 16 3	Lyra β Urfæ majoris α Urfæ majoris					
17	45 12 47 29	XXIII	46 38 48 56	48 5 50 22 $\frac{1}{2}$	} Sun				46	40
18	58 20 6 10	VII VIII	1 18 8 45	4 18	α Urfæ majoris β Cassiopeæ	64 45 $\frac{2}{3}$	69 0 10 $\frac{1}{2}$ a			

Day of the Month 1767.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Nov. 18	6 44 $\frac{1}{2}$	VIII 8 17		α Andromedæ					
	36 49	39 13	41 35 $\frac{1}{2}$	α Cassiopeæ					
	53 0	55 30		ϵ Ursæ majoris					
		57 20		Polaris	35 50 $\frac{1}{4}$	38 1 13 +	30,017		38 $\frac{1}{2}$
21	46 33	VI 49 32	52 32	α Ursæ majoris	64 45 $\frac{1}{2}$	69 0 10 +			
24	47 6 $\frac{1}{2}$	XXIII 48 35	50 2	} Sun				53	46
	49 26	50 54	52 18 $\frac{1}{2}$						
27	19 59	VI		Fomalhaut					
		26 1		α Ursæ majoris					
	27 44 $\frac{1}{2}$	29 16	30 48	β Pegasi					
	28 32	29 57	31 20	α Pegasi					
	41 6	XI 42 31	43 55	γ Tauri					
	49 31 $\frac{1}{2}$	50 58	52 24	ϵ Tauri					
	57 4	58 29	59 53 $\frac{1}{2}$	Aldebaran					
	33 22	XII 35 19	37 15 $\frac{1}{2}$	Capella					
	37 46	39 9	40 31	Rigel					
	45 48	47 22	48 54	β Tauri					
	47 2 $\frac{1}{2}$	48 25	49 46 $\frac{1}{2}$	γ Orionis					
	54 30	55 52	57 13	δ Orionis					
	58 46	XIII 0 9	1 29 $\frac{1}{2}$	ϵ Orionis					
	3 22	4 44	6 5 $\frac{1}{2}$	ζ Orionis					
	11 2	12 25	13 47 $\frac{1}{2}$	κ Orionis					
	16 52 $\frac{1}{2}$	18 15	19 37	α Orionis					
	2 49	XIV 4 36	6 19	Lyra, very doubtful.					
	9 0	10 26	11 50	Syrius					
	48 8	XXIII 49 36	51 3	} Sun				56	45
	50 28	51 55 $\frac{1}{4}$	52 22 $\frac{1}{2}$						
28	0 49	II 2 34	4 18	Lyra					
	16 4	VI 17 38 $\frac{1}{2}$	19 13	Fomalhaut					
		20 34	23 7	β Ursæ majoris					
		22 6	25 6 $\frac{1}{2}$	α Ursæ majoris					
	40 34 $\frac{1}{2}$	VIII 43 13 $\frac{1}{2}$	45 51 $\frac{1}{2}$	δ Cassiopeæ					
	7 19	IX 10 16 $\frac{1}{2}$	13 12	ϵ Cassiopeæ					
	37 11	XI 38 36	40 0	γ Tauri					
	45 36 $\frac{1}{2}$	47 3	48 29	ϵ Tauri					
	53 9	54 34	55 58 $\frac{1}{2}$	Aldebaran					
30	26 5 $\frac{1}{2}$	XXI 27 33	29 0	Arcturus					
		XXIII 50 43	52 11	} Sun				50 $\frac{1}{2}$	38 $\frac{1}{2}$
	51 35	53 3 $\frac{1}{2}$	54 31						
Dec. 1	6 17	VI 8 49	11 21	β Ursæ majoris					
	7 22 $\frac{1}{2}$	10 21		α Ursæ majoris					
	32 49	VIII 35 14	37 41 $\frac{1}{2}$	ζ Ursæ majoris					
	34 9	36 35	39 2	ξ Ursæ majoris					
2	0 17 $\frac{1}{2}$	XVIII 2 50	5 22	β Ursæ majoris					
	1 20 $\frac{3}{4}$	4 21	7 20	α Ursæ majoris	10 46 $\frac{2}{3}$	11 3 15			
		XX 1 55		Polaris	39 42	42 2 12	30,47	41 $\frac{1}{2}$	32
	50 2 $\frac{1}{2}$	XXIII 51 31	52 58	} Sun			30,5 1	48	34 $\frac{1}{2}$
	52 22	53 51 $\frac{1}{2}$	55 19						
3	57 25	XVIII 0 26	3 24	α Ursæ majoris					
	50 27	XXIII 51 55 $\frac{1}{2}$	53 24	} Sun			30,2	49	41
	52 48	54 16 $\frac{1}{2}$	55 44						

Day of the Month 1767.	Time by the Clock.				Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.		Third Wire.		Deg.	Parts of 96			
Dec. 7	38 33	VII	41 2 $\frac{1}{2}$		ϵ Urfæ majoris					
			42 30		Polaris					
		VIII	7 58 $\frac{1}{2}$		δ Cassiopeæ					
			11 44		ζ Urfæ majoris					
	49 44		51 12 $\frac{1}{2}$		α Arietis					
8	52 41 $\frac{1}{2}$	XXIII	54 11	55 38	} Sun			29,83	58	48
	55 3		56 32	58 0						
9	17 43 $\frac{1}{2}$	I	19 29	21 12	Lyra					
	34 58	V	37 29	40 2	β Urfæ majoris					
	36 2		39 1	42 2	α Urfæ majoris					
	44 26	VI	45 59	47 30	α Andromedæ					
		VII	34 36		Polaris	35 50 $\frac{1}{2}$	38 1 13 c	29,86		45 $\frac{1}{2}$
	41 54 $\frac{1}{2}$	VIII	43 23	44 51	α Arietis					
10	31 3	V	33 34	36 7 $\frac{1}{2}$	β Urfæ majoris					
	32 8		35 6	38 7	α Urfæ majoris					
	40 31	VI	42 4	43 36	α Andromedæ					
	45 32		46 56	48 20	γ Pegasi					
		VII	30 40		Polaris					
	37 59 $\frac{1}{2}$	VIII	39 28	40 56	α Arietis					
	50 11	X	51 35 $\frac{1}{2}$	53 0	γ Tauri					
	58 37	XI	0 3	1 29	ϵ Tauri					
	6 9		7 34	8 59	Aldebaran					
	28 58	XVII	31 31 $\frac{1}{2}$	34 3	β Urfæ majoris					
	30 2		33 3	36 0	α Urfæ majoris	10 46 $\frac{2}{3}$	11 3 15	29,825		39 $\frac{1}{2}$
		XIX	30 33		Polaris	39 41 $\frac{2}{3}$	42 2 12 c	29,92		39 $\frac{1}{2}$
	55 5		56 28	57 51	Spica Virginis					
	46 55 $\frac{1}{2}$	XX	48 24	49 50	Arcturus					
	53 39 $\frac{1}{2}$	XXIII	55 8	56 36 $\frac{1}{2}$	} Sun	75 26 $\frac{3}{4}$	80 3 15 $\frac{1}{2}$	29,975	53	42
	56 1		57 30	58 58		74 54 $\frac{2}{3}$	79 7 4 $\frac{2}{3}$			
11	9 54	I	11 39	13 23	Lyra	13 36 $\frac{3}{4}$	14 4 2 $\frac{1}{2}$			
	27 8	V	29 40	32 13	β Urfæ majoris					
	28 13 $\frac{1}{2}$		31 12 $\frac{1}{2}$	34 12 $\frac{1}{2}$	α Urfæ majoris	64 45 $\frac{1}{4}$	69 0 10	29,97		42
			35 6 $\frac{1}{2}$	36 30	α Pegasi					
	36 1	VI	38 36	41 8 $\frac{1}{2}$	β Cassiopeæ	5 39	6 0 3+W			
	36 36		38 9	39 40 $\frac{1}{2}$	α Andromedæ					
	6 40	VII	9 5	11 27	α Cassiopeæ	3 3-	3 2 0-W			
			26 46		Polaris	35 50 $\frac{2}{3}$	38 1 14			
			52 19		δ Cassiopeæ	6 48	7 2 1-W			
		VIII	19 22		ϵ Cassiopeæ	10 17 $\frac{3}{4}$	10 7 13 $\frac{2}{3}$ W			
12	24 19	V	27 17	30 17 $\frac{1}{2}$	α Urfæ majoris	64 45 $\frac{1}{3}$	69 0 10 c			
		VII	5 10 $\frac{1}{2}$	7 32	α Cassiopeæ	3 4 $\frac{1}{4}$	3 2 3 $\frac{1}{3}$ E			
	44 36 $\frac{1}{2}$	XXIII	56 5 $\frac{1}{2}$	57 34	} Sun			29,8	55	47
	56 59		58 27 $\frac{1}{2}$	59 56						
13		VI	30 19		α Andromedæ					
	28 12		30 46 $\frac{1}{2}$	33 19	β Cassiopeæ	5 41-	6 0 8 E			
	58 50	VII	1 14 $\frac{1}{2}$	3 37	α Cassiopeæ	3 4 $\frac{1}{2}$	3 2 3 $\frac{2}{3}$ E			
			16 36		γ Cassiopeæ	7 16	7 6 0 $\frac{1}{4}$ E			
			18 55		Polaris					
	41 50		44 29	47 6	δ Cassiopeæ	6 50-	7 2 4 $\frac{1}{4}$ E			
	8 33 $\frac{1}{2}$	VIII	11 32	14 27 $\frac{1}{2}$	ϵ Cassiopeæ	10 19 $\frac{1}{2}$	11 0 1 $\frac{2}{3}$ E			
	21 31		23 20	25 8	γ Andromedæ	11 0 $\frac{1}{3}$	11 5 14 $\frac{2}{3}$ W			
	26 14		27 43 $\frac{1}{2}$	29 11	α Arietis					
	38 26	X	39 51	41 15	γ Tauri					

Day of the Month 1767.	Time by the Clock.				Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.		Third Wire.		Deg.	Parts of 96			
Dec. 13	46 52 54 24	x 48 18 55 49 xi 32 40	49 44 57 13½ 34 36	ε Tauri Aldebaran Capella	6 29-	6 7 5 W	29,9	55	43	
14	54 56	vi 26 50 57 19½	59 42	β Cassiopeæ α Cassiopeæ	5 39½ 3 2⅔	6 0 4 W d 3 1 15⅔ W				
15	56 5½ 58 28½	xxiii 57 35½ 59 57½	59 4 1 26	} Sun			29,9	53½	46	
16	56 37	xxiii 58 7½	59 36	} Sun	75 48¾	80 6 15½				
17	58 0 46 24 57 30 12 31½ 43 10 58 14	o 0 30 o 48 9 v 59 51 vi 15 6 vii 0 56 3 10	1 58 49 53½ 2 14 17 38 47 57½	Lyra γ Urfæ majoris β Cassiopeæ α Cassiopeæ γ Cassiopeæ Polaris	75 16	80 2 5 +				
	26 9 53 53 5 51	28 49 55 51 viii 7 40 12 4	31 26 58 47 9 28 13 31½	δ Cassiopeæ ε Cassiopeæ γ Andromedæ α Arietis	6 48¼ 10 18 10 59	7 2 1 c W 10 7 14 c W 11 5 11½ E				
	23 29½ 22 47 31 12½ 38 44¼ 15 3 58 34	ix 25 34½ x 24 11 32 39 40 10 xi 17 0 59 56	27 38½ 25 35½ 34 5 41 34½ 18 56 1 17½	α Persei γ Tauri ε Tauri Aldebaran Capella α Orionis	3 10¼	3 3 1 E				
17	57 8	xxiii 58 38	0 6	} Sun	6 27½	6 7 2—E				
18	59 30½ 42 29½ 53 5 5 30 6 17½ 9 12 14 13 55 30 6 40 27 17½ 34 50	o 1 0 o 44 14 i 54 28 iv 59 19½ v 7 2 vi 10 45 15 37½ 41 40 57 59½ 59 20 viii 8 9 x 28 44 36 15	2 28 45 58 55 49½ 8 33 9 6 12 16 17 0½ 37 39½	Lyra α Aquilæ Fomalhaut β Pegasi α Pegasi α Andromedæ γ Pegasi α Cassiopeæ ε Urfæ majoris Polaris α Arietis ε Tauri Aldebaran	75 50½ 75 17½ 13 36¾ 82 55½ 25 20¾ 25 50½ 36 9½	80 7 3½ 80 2 8½ 13 4 2⅔ 88 3 10¾ 27 0 5 38 1 13 c 38 4 8 c	29,47	56	43½	
18	57 38½	xxiii 59 8		} Sun						
19	0 1½									
19	58 9½	xxiii 59 39	1 7	} Sun	75 53	80 7 9½	29,385	50	43	
20	0 31 34 40	o 2 1 o 36 24½	3 30 38 8	Lyra	75 20 13 36⅔	80 2 13⅔ 13 4 2½				
22	59 11 1 34 51 0	o 0 41 3 3½ vii 52 29 viii 49 54 ix 6 0	2 10 4 32 53 56½ 8 3	} Sun α Arietis β Urfæ minoris α Persei	75 53½ 75 20½	80 7 10 + 80 2 15⅓	29,965	48	38 33½ 33½	
23	59 42½ 2 6 22 54 49 36	o 1 12 3 34½ o 24 39 v 51 9	2 41 5 3½ 26 22½ 52 41	} Sun Lyra α Andromedæ			30,11	51	33½	

Day of the Month 1767.	Time by the Clock.				Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.		Third Wire.		Deg.	Parts of 96			
Dec. 23	54 37	V	56	I	57 25	γ Pegasi				
		VI	39	42		Polaris	35 50 $\frac{3}{4}$	38 1 14 c	30,125	30 $\frac{1}{2}$
	47 5	VII	48	33 $\frac{1}{2}$	50 1	α Arietis	29 50	31 6 8 $\frac{1}{2}$		
	40 7 $\frac{1}{2}$	VIII	42	22	44 36	γ Persei	0 23 $\frac{1}{4}$	0 3 5 $\frac{1}{2}$ Ea		
	59 58 $\frac{1}{2}$	IX	2	4	4 8	α Persei	3 12	3 3 4 $\frac{1}{2}$ Wd		
	59 16	X	0	41	2 5	γ Tauri				
	7 42		9	9	10 34	ϵ Tauri				
	15 14		16	40	18 4	Aldebaran	36 10-	38 4 9 -		
	51 32 $\frac{1}{2}$		53	30	55 26	Capella	6 27 $\frac{1}{2}$	6 7 2 c E		
		XVIII	35	33 $\frac{1}{2}$		γ Cassiopeæ				
			39	35		Polaris	39 42	42 2 12 $\frac{3}{4}$ a	30,15	27 $\frac{2}{3}$
		XIX				δ Cassiopeæ	68 43	73 2 7 a		
			5	34		Spica Virginis				
			7	2 $\frac{1}{2}$		ζ Ursæ majoris				
			8	23		ζ Ursæ majoris				
			30	49		η Ursæ majoris				
			42	15	44 3 $\frac{1}{2}$	γ Andromedæ				
	56 1		57	29	58 55	Arcturus				
24	0 14	O	1	43	3 12	} Sun			30,19	48 31
	2 36		4	5 $\frac{1}{2}$						
27	1 44	O	3	14	4 43	} Sun			29,4	39 27
	4 6 $\frac{1}{2}$		5	36	7 4 $\frac{1}{2}$					
28		VI	17	44		γ Cassiopeæ				
			19	52		Polaris	35 50 $\frac{3}{4}$	38 1 13 $\frac{1}{2}$	29,47	27 $\frac{1}{2}$
29	3 46	O	4	15	5 43	} Sun			29,625	40 $\frac{1}{2}$ 27
	5 9		6	38	8 7					
	23 33	VII	25	1	26 29	α Arietis	29 50c	31 6 9 +		
	36 27 $\frac{1}{2}$	VIII	38	33	40 36 $\frac{1}{4}$	α Persei	3 10 $\frac{1}{2}$	3 3 1 $\frac{1}{2}$ E		
	51 42	IX	53	7 $\frac{1}{2}$	54 32	Aldebaran	36 10c	38 4 9 $\frac{2}{3}$		
	28 1	X	29	58	31 54 $\frac{1}{4}$	Capella	6 27 $\frac{3}{4}$	6 7 2 $\frac{1}{3}$ Ea	29,75	26
	55 27	XXIII	57	11 $\frac{1}{2}$	58 55	Lyra				
30	3 15	O	4	45	6 13 $\frac{1}{2}$	} Sun	75 36 $\frac{1}{2}$	80 5 3 $\frac{1}{2}$	29,8	41 $\frac{1}{2}$ 26
	5 38		7	7 $\frac{1}{2}$	8 36		75 3 $\frac{1}{2}$	80 0 8 c		
	22 8 $\frac{1}{2}$	V	23	41 $\frac{1}{2}$	25 13	α Andromedæ				
	27 10		28	34		γ Pegasi				
		VI	9	57 $\frac{1}{2}$		γ Cassiopeæ				
			11	47		Polaris	35 50 $\frac{4}{5}$	38 1 14 $\frac{1}{4}$ d	29,75	24 $\frac{1}{2}$
	19 38	VII	21	7	22 34	α Arietis	29 49 $\frac{3}{4}$	31 6 8 +		
	12 40	VIII	14	55 $\frac{1}{2}$	17 9 $\frac{1}{2}$	γ Persei	0 22c	0 3 2 + W		
			18	35 $\frac{1}{2}$		β Ursæ minoris				
	32 32		34	36 $\frac{1}{2}$	36 40 $\frac{1}{2}$	α Persei	3 10 $\frac{1}{2}$	3 3 1 $\frac{1}{3}$ E		
	31 49	IX	33	14	34 37 $\frac{1}{2}$	γ Tauri				
	40 15		41	41 $\frac{1}{2}$	43 6 $\frac{1}{2}$	ϵ Tauri				
	47 47		49	12	50 37	Aldebaran	36 10-	38 4 9 $\frac{1}{3}$		
	24 4	X	26	2	27 58	Capella	6 27 $\frac{1}{2}$	6 7 2 e		
	28 30		29	52	31 14	Rigel				
	37 46 $\frac{1}{2}$		39	8 $\frac{1}{2}$	40 30	γ Orionis	46 4-	49 1 1 $\frac{1}{4}$		
			46	36	47 56	δ Orionis	52 40 $\frac{1}{4}$	56 1 7 +		
	49 30		50	52 $\frac{1}{2}$	52 13	ϵ Orionis				
	54 5 $\frac{1}{2}$		55	28	56 49	ζ Orionis				
	1 45	XI	3	9	4 31	α Orionis				
	7 36		8	59	10 21	α Orionis	44 50 $\frac{2}{3}$	47 6 10 $\frac{1}{2}$	29,73	23
		XVIII				Polaris	39 42c	42 2 12 $\frac{2}{3}$ a	29,71	22 $\frac{1}{2}$
	33 23		36	0 $\frac{1}{2}$		δ Cassiopeæ				

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	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Dec. 30		XVIII 38 7 XIX 30 2 XX 10 57	39 29½ 31 28 21 31½	Spica Virginis Arcturus β Ursæ minoris					
31	3 46 6 7½ 8 45½ 28 36	o 5 14½ 7 37 VIII 11 0 30 41½	6 43 9 5 13 13½ 32 45½	} Sun γ Persei α Persei	o 23½ 3 10½	o 3 5½ E 3 3 1¼ E	29,77 29,89	41	27 25½
1768. January 2	4 43 7 5 23 25 51 31+	o 6 12 8 35 VI o 10 26 4½ 29 54½ 31 14½ 53 39— 57 5 VII 4 55 9 20 VIII 3 9+ 6 46— x 22 51 14 16 18 7 26 18½ 27 23 34 50 39 6½ 43 42 51 24 57 13 o 45½ 3 9— 12 48 12 52+ 15 25+	7 40 10 2½ 28 42 24 55 16 12½ 19 29 27 51 28 44+ 36 11 40 28 45 3+ 52 46 58 35— 2 17½ 4 41+ 14 16— 14 20+ 16 53	} Sun Polaris δ Cassiopeæ ζ Ursæ majoris ξ Ursæ majoris η Ursæ majoris β Arietis γ Andromedæ α Arietis γ Persei β Ursæ minoris α Persei Capella Rigel β Tauri γ Orionis δ Orionis ε Orionis ζ Orionis κ Orionis α Orionis } Moon } Saturn η Gemini	75 22½ 74 49½ 35 50½ 6 48 29 50c o 22c 3 10½ 6 27½ 46 3¼ 52 40½ 53 32½ 54 25½ 61 56½ 75 10½ 74 37½ 9 3½ 11 25½ 74 56½ 74 24½ 73 33½ 78 3 11¼	80 3 3½ 79 6 8¼ 38 1 14½ 7 2 1 c 31 6 9 + o 3 2½ W 3 3 1½ 6 7 2 c 49 1 1 c 56 1 7½ 57 o 15½ 57 7 1 c 66 o 9¼ 80 1 9 c 79 4 14 c	29,62 29,85	37½ 37	25 20 18 17
3	5 12 7 34	o 6 41½ 9 3	8 9+	} Sun			29,915	38	26
4	5 40+ 8 2	o 7 9 9 31	8 37+ 10 59	} Sun	75 10½ 74 37½	80 1 9 c 79 4 14 c	30,105	40	22½
5	8 28½	o 9 57	9 3½ 11 25½	} Sun			30,1	35½	21½
6	6 35 8 56½	o 8 4+ 10 26—	9 32 11 53½	} Sun	74 56½ 74 24½	79 7 11 79 3 o	29,835	38½	25
12	11 30	o 12 58¾	12 5½ 14 25½	} Sun U. L.	73 33½	78 3 11¼	29,8	44	33½
14		v 42 52 44 12		ζ Ursæ majoris ξ Ursæ majoris			29,435	51	40
15	o 34½ 12 9—	VI 2 42 6 7 13 58 18 21—	4 50½ 7 33 15 45+ 19 49½	η Ursæ majoris β Arietis γ Andromedæ α Arietis	29 50	31 6 9 +			

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.	
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96				
Jan. 16	10 41	o 12 9—	13 36	} Sun	73 24 $\frac{1}{4}$	78 2 6 $\frac{1}{2}$	29,8	50	39 $\frac{1}{2}$	
	13 0+	14 28	15 55		72 51 $\frac{1}{2}$	77 5 12 c				
		v 5 0		Polaris	35 50 $\frac{2}{3}$	38 1 14 $\frac{1}{3}$	29,855	51 $\frac{1}{2}$	39	
	15 35	17 14	18 53—	β Andromedæ						
	28 31	31 11	33 48 $\frac{1}{2}$	δ Cassiopeæ			29,905	51 $\frac{1}{2}$	48	
		35 1		ζ Urfæ majoris						
		36 22		ζ Urfæ majoris						
	55 15	58 13+	1 8	ϵ Cassiopeæ						
	56 38 $\frac{1}{2}$	58 47	59 55	η Urfæ majoris						
		vi 10 2		γ Andromedæ						
		14 26 $\frac{1}{2}$	15 54	α Arietis	29 50—	31 6 8 $\frac{1}{2}$				
	6 0	vii 8 15 $\frac{1}{2}$	10 29	γ Persei	0 23 $\frac{1}{2}$	0 3 5 $\frac{1}{3}$ E				
		11 55—	17 12+	β Urfæ minoris	52 40+	56 1 7 $\frac{1}{2}$				
	25 52+	27 57	30 1	α Persei	3 10+	3 3 0 $\frac{1}{2}$ d				
	33 7	37 38 $\frac{1}{2}$	42 14 $\frac{1}{2}$	γ Urfæ minoris						
	36 55 $\frac{1}{2}$	41 27	46 2 $\frac{1}{2}$	γ Urfæ minoris	55 6 $\frac{1}{2}$	58 6 5 c				
	25 9	viii 26 34 $\frac{1}{2}$	27 59—	γ Tauri						
	33 36	35 2	36 27	ϵ Tauri						
	41 8	42 33 $\frac{1}{2}$	43 57	Aldebaran	36 10 c	38 4 9 $\frac{1}{2}$				
		ix 19 22 $\frac{1}{2}$	21 18 $\frac{1}{2}$	Capella	6 27 $\frac{1}{3}$	6 7 2—				
		23 13	24 35+	Rigel	60 39 $\frac{2}{3}$	64 5 10 $\frac{1}{2}$				
	29 51+	31 25 $\frac{1}{2}$	32 57+	β Tauri						
	31 7	32 29+		γ Orionis	46 3 $\frac{3}{4}$	49 1 2 c				
	38 34	39 56+	41 17	δ Orionis	52 40+	55 6 8 —				
		44 12 $\frac{1}{2}$	45 33	ϵ Orionis						
	47 26+	48 48+	50 9 $\frac{1}{2}$	ζ Orionis						
		56 30		κ Orionis	61 1 $\frac{1}{2}$	65 4 10 —				
	0 57	x 2 20—	3 41 $\frac{1}{2}$	α Orionis	44 50 $\frac{1}{2}$	47 6 10 $\frac{1}{2}$				
	11 58 $\frac{1}{2}$		14 55	Saturn	29 41+	31 5 5 —				
		54 30		Sirius						
	19	11 40 $\frac{1}{2}$	13 8 $\frac{1}{2}$	14 35 $\frac{1}{2}$	} Sun	72 48 $\frac{1}{3}$				77 6 5 c
		14 0	15 28	16 55		72 15 $\frac{1}{4}$	77 0 10 c			
		12 4	iv 53 5	v 33 27	Polaris			29,6	52 $\frac{1}{2}$	37 $\frac{1}{2}$
		3 49	v 5 28 $\frac{1}{2}$	7 6+	β Andromedæ					
		1 12—	vi 2 40	4 8	α Arietis	29 50 c	31 6 9 +			
		54 55 $\frac{1}{2}$	vii 0 10	5 28 $\frac{1}{2}$	β Urfæ minoris	52 40+	56 1 7 $\frac{1}{2}$			
		14 6—	16 10+	18 13 $\frac{1}{2}$	α Persei	3 10 $\frac{2}{3}$	3 3 1 $\frac{1}{3}$			
		25 10	29 42	34 16—	γ Urfæ minoris	55 6 $\frac{1}{2}$	58 6 5 c			
		13 23 $\frac{1}{2}$	viii 14 48	16 12 $\frac{1}{2}$	γ Tauri					
		29 21 $\frac{1}{2}$	30 46 $\frac{1}{2}$	32 11	Aldebaran	36 10—	38 4 9 +			
5 39		ix 7 36+	9 32+	Capella	6 27 $\frac{1}{2}$	6 7 2				
10 4		11 27	12 49+	Rigel	60 40—	64 5 11 +				
18 5 $\frac{1}{2}$			21 11	β Tauri						
19 20+		20 43	22 4 $\frac{1}{2}$	γ Orionis	46 3 $\frac{3}{4}$	49 1 2 c				
26 48		28 10	29 31	δ Orionis	52 40 $\frac{1}{4}$	56 1 8 —				
31 4+		32 26+	33 47 $\frac{1}{2}$	ϵ Orionis						
35 40		37 2	38 24—	ζ Orionis						
43 20		44 43 $\frac{1}{2}$		κ Orionis	61 1 $\frac{1}{2}$	66 0 10				
48 29 $\frac{1}{2}$		50 26		β Aurigæ						
49 11		50 33 $\frac{1}{2}$	51 55	α Orionis	44 50 $\frac{2}{3}$	47 6 11 c	29,535	51	36 $\frac{1}{2}$	
22		43 7	vi 48 23	53 41	β Urfæ minoris	52 40 $\frac{1}{2}$	56 1 7 $\frac{2}{3}$	29,2	47 $\frac{1}{2}$	38
		2 20	vii 4 25 $\frac{1}{2}$	6 29	α Persei	3 10 $\frac{1}{2}$	3 3 1			
			14 6		γ Urfæ minoris			29,2	47 $\frac{1}{2}$	38
		13 22 $\frac{1}{2}$	17 55—	22 30—	γ Urfæ minoris	55 7 c	58 6 5 $\frac{1}{2}$			
		42 49—	xviii 46 7	51 22+	β Urfæ minoris	22 52 $\frac{1}{3}$	24 3 3			
			xix 2 33	4 38	α Persei	78 41 $\frac{1}{2}$	83 7 8 $\frac{1}{3}$			

* The bisection at all three wires.

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Jan. 22	11 8 57 10	XIX 15 42 XX 58 39 XXII 23 6	20 14½ 0 5½ 24 50—	γ Ursa minoris Venus Lyra	20 26— 72 0½	21 6 5⅓ d 76 6 9 —	29,16	43	36
23	15 11	0 14 20 16 38	15 45+ 18 4	} Sun	71 55— 71 22 c	76 5 11 + 76 1 0⅓	29,18	46½	37
24	13 9— 15 27 13 31½	0 14 35½ 16 54 XXII 15 16+	16 2 18 19½ 16 59½	} Sun Lyra	71 41— 71 7½	76 3 11½ 75 7 0 c	29,26	49	38
26	13 38½ 15 56	0 17 22+	16 30+ 18 48	} Sun			29,425	53½	44
*	21 33½ 33 46	IV 25 [15 V 23 0 35 15	V 6 6 24 27— 36 42½	Polaris β Arietis α Arietis			29,607	54	42½
	27 28½ 46 40½ 52 43 45 58½	VI 2 41½ 32 42 48 45½ VII 2 15½	38 2 50 49 6 50+ 48 47	Moon's First L.L. Limb β Ursa minoris α Persei γ Ursa minoris	29 50 33 29— 52 40+ 3 10½ 55 7—	31 6 9 + 35 5 11 56 1 7⅓ 3 3 1⅓ a 58 6 5 c			
	1 56 38 14 42 39 50 40 51 55+	VIII 3 21 40 11½ 44 2 52 14 53 18	4 45 42 7 45 24 53 46 54 39½	γ Tauri Aldebaran Capella Rigel β Tauri	36 10+ 6 27½ 60 40—	38 4 10 c 6 7 2 — 64 5 11 c			
	59 23 3 39 8 15 15 55 21 46 30 9 13 53	IX 0 45 5 1 9 36 17 18 23 9 31 37 X 15 20	2 6 6 22 10 59 18 41 24 30 33 4 16 43	γ Orionis δ Orionis ε Orionis ζ Orionis α Orionis Saturn Sirius	52 40¼ 52 40¼ 44 50¾ 29 40+ 68 34½	56 1 8 c 56 1 8 c 47 6 11 c 31 5 1⅓ 73 1 4	29,74	54	41
28	14 5 16 21½	0 15 31	16 56½ 19 14	} Sun	70 40½ 70 7½	75 3 2⅓ 74 6 7 +	29,6	52	45
30	14 27+ 16 44	0 15 53½ 18 10+	17 18½ 19 35	} Sun			29,812	52	48
*	11 47 31 0	IV 10 [10 VI 17 2 33 5	50 36 22 22	Polaris β Ursa minoris α Persei	52 40¼ 3 10¼	56 1 8 — 3 3 1⅓ d	29,865	53½	45
31	14 37 16 54	0 16 3½ 18 20	17 28+ 19 45—	} Sun	69 52 c 69 19—	74 4 3⅓ 73 7 8 c	29,88	54	44½
Feb. 3	2 25 56 5½ 15 19½	V 3 54 VI 1 21 17 25 30 54	5 22 6 40 19 28½ 35 27½	α Arietis β Ursa minoris α Persei γ Ursa minoris	52 40+ 3 10½ 55 6⅓	56 1 7⅓ 3 3 1⅓ 58 6 5 c	29,89	44	33
	36 54	VII 32 0— VIII 38 16—	33 25— 39 37	Aldebaran ζ Orionis					
4	10 42 19 7+ 26 40 2 57+ 7 23	VII 12 7 20 34 28 5 VIII 4 55 8 45½	13 30+ 22 0 29 29½ 6 51+ 10 8	γ Tauri ε Tauri Aldebaran Capella Rigel	36 10 c 6 27½ 60 39½	38 4 9½ 6 7 2 c 64 5 10½	30,065	50	36½

* The appulse to and leaving of the center wire, the bisection at the third wire.

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Feb. 4	16 39 $\frac{1}{2}$	VIII 18 1+	19 23 $\frac{1}{2}$	γ Orionis	46 3 $\frac{2}{3}$	49 1 1 c			
	24 7	25 29—	26 50	δ Orionis	52 40+	56 1 7 +			
	27 36 $\frac{1}{2}$	29 5	30 32	ζ Tauri					
	28 23	29 45	31 6	ϵ Orionis	53 33 c	57 0 15 $\frac{2}{3}$			
	32 59—	34 21	35 42	ζ Orionis	54 16—	57 7 1 c			
		42 2 $\frac{1}{2}$	43 25—	κ Orionis	61 56 $\frac{1}{2}$	66 0 9 $\frac{1}{2}$			
	46 29+	47 52	49 14—	α Orionis	44 50 $\frac{1}{2}$	47 6 11 —			
	38 37	IX 40 3—	41 27	Sirius	68 34 $\frac{1}{2}$	73 1 4 c			
	53 3 $\frac{1}{2}$	54 37	56 9+	ϵ Canis majoris	80 47—	86 1 5 $\frac{2}{3}$			
		X 4 2	5 32	δ Canis majoris	78 10	83 3 1 c			
	18 10 $\frac{1}{2}$	19 34	20 56—	β Canis minoris					
	23 7	24 44—	26 20	Castor	19 49+	21 1 2 c			
	30 44	32 6 $\frac{2}{3}$	33 28 $\frac{1}{2}$	Procyon	46 23 c	49 3 13 +			
	34 29	36 2	37 34	Pollux	23 37 $\frac{1}{3}$	25 1 9	30,11	50	35
	49 52 $\frac{1}{2}$	XVII 55 13	0 26	β Ursa minoris	22 52 $\frac{1}{3}$	24 3 3 c			
	9 33—	XVIII 11 36	13 41 $\frac{1}{2}$	α Persei	78 41	83 7 8 —			
		24 46		γ Ursa minoris	20 26 $\frac{1}{2}$	21 6 7 d	30,205	44	33
		36 28		α Serpentis					
	5 15 16—	O 16 40+	18 4	} Sun	68 24 $\frac{1}{2}$	72 7 12 +	30,292	50	37
	17 31	18 56+	20 20+		67 51 $\frac{1}{2}$	72 3 2 c			
	48 16 $\frac{1}{2}$	V 53 31	58 51+	β Ursa minoris	52 40 $\frac{1}{2}$	56 1 7 $\frac{2}{3}$	30,337	50	37 $\frac{1}{2}$
		54 54 $\frac{1}{2}$	56 40+	Medusæ caput					
	7 29 $\frac{1}{2}$	VI 9 34+	11 37 $\frac{1}{2}$	α Persei	3 10 $\frac{2}{3}$	3 3 1 $\frac{1}{2}$			
	18 33	23 4	27 40—	γ Ursa minoris	55 7 c	58 6 5 $\frac{1}{2}$			
	6 47	VII 8 12	9 36—	γ Tauri					
		16 39	18 4 $\frac{1}{2}$	ϵ Tauri					
	22 45	24 10	25 34	Aldebaran	36 10—	38 4 9 $\frac{1}{2}$			
	59 2+	VIII 1 0	2 56	Capella	6 27 $\frac{1}{3}$	6 7 1 $\frac{2}{3}$			
		4 50	6 12 $\frac{1}{2}$	Rigel	60 40—	64 5 11 c			
	11 30	13 2 $\frac{1}{2}$	14 35	β Tauri					
	12 44	14 6	15 28	γ Orionis	46 4—	49 1 2 c			
	20 11	21 33+	22 54 $\frac{1}{2}$	δ Orionis	52 40 $\frac{1}{3}$	56 1 7 $\frac{1}{2}$			
	24 28	25 50	27 11	ϵ Orionis	53 33 c	57 1 0 —			
	29 3 $\frac{1}{2}$	30 26	31 47	ζ Orionis	54 16 c	57 7 1 c			
	36 44—	38 7—	39 29	κ Orionis	61 57—	66 0 10 c			
	42 34 $\frac{1}{2}$	43 56 $\frac{2}{3}$	45 18 $\frac{1}{2}$	α Orionis	44 50 $\frac{2}{3}$	47 6 11 —			
	48 53+	50 22	51 49 $\frac{1}{2}$	} Saturn	29 38 $\frac{2}{3}$	31 4 15 $\frac{1}{2}$			
	48 57+	50 26	51 54	Sirius	68 35—	73 1 4 c			
	34 42+	IX 36 7 $\frac{1}{2}$	37 31 $\frac{1}{2}$	ϵ Canis majoris	80 46 $\frac{3}{4}$	86 1 6 —			
		50 41 $\frac{1}{2}$	52 14	δ Canis majoris	78 10	83 3 1 $\frac{1}{2}$			
	58 35	X 0 7—	1 37	β Canis minoris					
	14 15 $\frac{1}{2}$	15 39—	17 0+	Castor	19 49 c	21 1 2 c			
	19 12	20 49—	22 25	Procyon	46 23	49 3 13 $\frac{1}{2}$			
	26 49 $\frac{1}{2}$	28 12	29 34—	Pollux	23 37 $\frac{1}{2}$	25 1 9 c	30,33	51	32 $\frac{1}{2}$
	30 33 $\frac{1}{2}$		33 39 $\frac{1}{2}$	β Ursa minoris	22 52 $\frac{1}{2}$	24 3 3 c	30,27	44 $\frac{1}{2}$	34
	45 59	XVII 51 18	56 33 $\frac{1}{2}$	Medusæ caput					
		52 18 $\frac{1}{2}$	44 22	α Persei	78 41	83 7 8 c			
	5 38—	XVIII 7 42—	9 47	γ Ursa minoris	20 26—	21 6 5 $\frac{1}{3}$ a			
	16 16	20 52 $\frac{1}{2}$	25 24	α Coronæ					
	23 2	24 34 $\frac{1}{2}$	26 6	α Serpentis					
	31 10 $\frac{1}{2}$	32 33+	33 55 $\frac{1}{2}$	β Serpentis					
		35 10	36 35	ϵ Serpentis					
	37 35	38 57	40 18+	η Draconis					
	17 26 $\frac{1}{2}$	XIX 20 22		Capella	9 49 c	10 3 12 $\frac{1}{2}$	30,27	48	35
	57 10 $\frac{1}{2}$	59 7	1 5						
6	15 20	O 16 45 $\frac{1}{2}$	18 10—	} Sun	68 6 $\frac{1}{4}$	72 5 3 +	30,3	51 $\frac{1}{2}$	42
	17 36	19 1—	20 25 $\frac{1}{2}$		67 33 $\frac{1}{3}$	72 0 8 c			

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Feb. 12		VI 49 13	50 38	α Tauri					
		56 44+	58 8 $\frac{1}{2}$	Aldebaran					
	31 37	VII 33 34	35 30+	Capella	6 27 $\frac{1}{3}$	6 7 2 -			
	36 2	37 25	38 47	Rigel					
	44 3 $\frac{1}{2}$	45 18 $\frac{1}{2}$	47 9	β Tauri					
	45 37	46 41	48 2	γ Orionis	46 4 c	49 1 2 -	29,506	59	50
	52 46	54 8	55 29	δ Orionis	52 40 $\frac{1}{2}$	56 1 7 $\frac{2}{3}$			
	57 2+	58 24 $\frac{1}{2}$	59 46-	ϵ Orionis	53 33-	57 1 0 -			
		57 44 $\frac{1}{2}$		ζ Tauri					
	1 38 $\frac{1}{2}$	VIII 3 0 $\frac{1}{2}$	4 21 $\frac{1}{2}$	ζ Orionis	54 16	57 7 1 $\frac{1}{2}$			
	15 9	16 31+	17 53	α Orionis	44 50 $\frac{3}{4}$	47 6 11 c			
	20 28 $\frac{1}{2}$	21 57	23 25	} Saturn					
	20 32	22 1-	23 28		29 37 $\frac{1}{2}$	31 4 13 c			
	39 45 $\frac{1}{2}$	XIX 31 41+	33 39 $\frac{1}{2}$	Capella			29,68	54	47
	49 23	50 57	52 30	Moon Second Limb					
	59 5+	XXI 0 50	2 34+	Lyra			29,71	56	48
13		0 16 59 $\frac{1}{2}$	18 23	} Sun	65 51 $\frac{1}{3}$	69 2 0 c			
					65 18 $\frac{1}{3}$	69 5 5 -	29,73	59	51
	14 37	VII 16 25	18 12	ζ } Hædi					
	18 34 $\frac{1}{2}$	20 23 $\frac{1}{2}$	22 11	η }					
	25 12	26 34		β Eridani					
	27 42	29 39 $\frac{1}{2}$	31 36	Capella	6 27 $\frac{1}{3}$	6 7 2 - a			
	32 6	33 30-	35 51	Rigel					
	41 23	42 46	44 7	γ Orionis	46 4 c	49 1 2 c			
	48 51-	50 12+	51 34-	δ Orionis	52 40 $\frac{1}{2}$	56 1 7 $\frac{2}{3}$			
	53 7+	54 29	55 50+	ϵ Orionis	53 33 c	57 0 15 $\frac{2}{3}$			
	57 43	59 5	0 26 $\frac{1}{2}$	ζ Orionis	54 16	57 7 2 -			
	5 23	VIII 6 46	8 8	α Orionis	61 57-	66 0 10 +			
	11 13+	12 36	13 58-	α Orionis	44 50 $\frac{3}{4}$	47 6 11 c			
	16 27	17 56-	19 24	} Saturn					
	16 30 $\frac{1}{2}$	17 59	19 27		29 37 $\frac{1}{2}$	31 4 13 -	29,81	56 $\frac{1}{2}$	48 $\frac{1}{2}$
	40 58	42 24 $\frac{1}{2}$		β Canis majoris					
18	15 24	0 16 48 $\frac{1}{2}$	18 10 $\frac{1}{2}$	} Sun			29,942	53 $\frac{1}{2}$	41
	17 37	19 2	20 24						
21	15 9-	0	17 55 $\frac{1}{2}$	} Sun	63 4-	67 2 3 -			
		18 44 $\frac{1}{2}$	20 7		62 30 $\frac{3}{4}$	66 5 7 $\frac{1}{4}$	29,582	54 $\frac{1}{2}$	51
	32 2 $\frac{1}{2}$	VIII 33 28	34 52 $\frac{1}{2}$	Sirius	68 35-	73 1 4 +	29,765	56	50
	46 28 $\frac{1}{2}$	48 2	49 34	δ Canis majoris					
	55 56	57 27 $\frac{1}{2}$	58 57	ϵ Canis majoris					
	11 36	12 59		β Canis minor.					
	16 33	18 10-	19 46-	Castor					
	24 10	25 33	26 54	Procyon					
	27 54 $\frac{1}{2}$	29 28	31 0+	Pollux					
23	48 34	VI 50 31 $\frac{1}{2}$	52 27 $\frac{1}{2}$	Capella					
	52 58 $\frac{1}{2}$	54 21	55 43 $\frac{1}{2}$	Rigel			29,52	56 $\frac{1}{2}$	50
	1 0	VII 2 34	4 6	β Tauri					
	2 15+	3 37 $\frac{1}{2}$	4 59	γ Orionis					
	9 42	11 4 $\frac{1}{2}$	12 25 $\frac{1}{2}$	δ Orionis					
	13 58 $\frac{1}{2}$	15 21	16 42	ϵ Orionis					
	18 35	19 57	21 18	ζ Orionis					
		38 7-		} Saturn					
		38 9 $\frac{1}{2}$			29 36	31 4 10 c			
24		VI 9 46+	11 11-	Aldebaran					
	44 40		48 34	Capella					

ASTRONOMICAL OBSERVATIONS.

17

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Feb. 24	49 4	VI 50 27—	51 49—	Rigel			29,69	56½	49
25	36 56 44 34 47 59	XI 38 20 46 4 49 27	39 44 47 33+ 50 54½	Regulus ζ Leonis γ Leonis			29,8	52	44
27	32 54 45 21 46 36+ 58 19½ 16 26	VI 34 52 46 54+ 47 57½ 55 25 VII 17 48½ 22 25 22 28 VIII 39 46½ IX 2 4— 5 59½	36 48½ 58 26 56 46 3 25— 7 31	Capella β Tauri γ Orionis δ Orionis ε Orionis α Orionis } Saturn Moon's First Limb. U.L. Procyon Pollux	29 17+	31 1 15	29,89	56	49
28	14 11 16 22— 33 23½ 50 7½ 54 24 17 1 17 4½ 49 9	O 15 34 17 44½ VI 34 47— 51 30 55 46½ VII 0 22— 13 53 18 31 18 34+ VIII 50 46	16 56 19 6½ 36 9— 52 51— 57 7½ 15 15 52 21½	} Sun Rigel δ Orionis ε Orionis ζ Orionis α Orionis } Saturn Castor			29,97	54	50
29	14 0	O 15 23 17 33+	16 45 18 55	} Sun			29,7	55	53
March 2	13 37½ 15 47	O 17 10—	16 22	} Sun			29,85	54	48½
3	13 25+ 15 35 56 51 1 29 1 31½ 33 29 41 7— 44 51	O 14 48 16 58 VI 52 23½ 58 14 VII 2 57 3 1 50 24+ VIII 35 6 42 29 46 24½	16 9½ 18 19½ 53 46½ 59 35+ 4 26+ 4 29+ 36 42— 43 51— 47 56	} Sun α Orionis α Orionis } Saturn Sirius Castor Procyon Pollux	44 50½ 29 34¼	47 6 10⅓ 31 4 5	30,305 30,39	51 51	36 37
4	9 24 13 49½ 21 52— 23 6 30 33 34 50— 39 26—	V 34 32½ VI 11 22 15 12½ 23 24½ 24 28½ 31 55+ 36 12 40 48 XVIII 9 28—	35 56½ 13 18½ 16 34 25 50 33 17— 37 33 42 9 11 26	Aldebaran Capella Rigel β Tauri γ Orionis δ Orionis ε Orionis ζ Orionis Capella d			30,42	53	38
5	5 29	V 30 37— VI 7 27+	32 1 9 23	Aldebaran Capella					

E

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
March 5	9 54—	VI 11 17—	12 39	Rigel					
	17 56	19 29	21 1 $\frac{1}{2}$	β Tauri					
	19 10 $\frac{1}{2}$	20 33	21 55	γ Orionis					
	26 38	28 0	29 21	δ Orionis					
	30 54 $\frac{1}{2}$	32 16+	33 38—	ϵ Orionis					
	35 30+	36 52 $\frac{1}{2}$	38 13 $\frac{1}{2}$	ζ Orionis					
	43 10+	44 33 $\frac{1}{2}$	45 56	α Orionis					
	49 1	50 24—	51 45	α Orionis					
	53 45—	55 13 $\frac{1}{2}$	56 41+	} Saturn					
	53 48	55 16 $\frac{1}{2}$	56 44+						
	41 8+	VII 42 34—	43 58 $\frac{1}{2}$	Sirius					
	25 39—	VIII 27 15 $\frac{1}{2}$	28 52	Castor					
	33 16	34 38	35 59 $\frac{1}{2}$	Procyon					
	37 1—	38 34—	40 6 $\frac{1}{2}$	Pollux					
	0 19	XI 1 45		η Leonis					
		3 6—	4 29	Regulus			30,27		
	9 19+	10 49		ζ Leonis					
	12 45	14 13	15 40—	γ Leonis					
		XIII 36 36	37 57	γ Virginis					
	44 14	45 40	47 4	} Moon					
	46 14—	47 39	49 3						
7		53 5		Polaris					
	18 11	XIV 19 34+	20 56 $\frac{1}{2}$	Spica Virginis					
	27 7—	28 30—	29 51	} Jupiter					
	27 10 $\frac{1}{2}$	28 33+	29 54 $\frac{1}{2}$						
		XV 11 29 $\frac{1}{2}$	12 56	Arcturus			30,23	47	34 $\frac{1}{2}$
		VII	36 8	Sirius					
		VIII 19 25 $\frac{1}{2}$	21 2	Castor					
	25 26—	26 48	28 10—	Procyon					
		30 44—	32 16—	Pollux					
9	17 18	XIX 19 3—	20 46 $\frac{1}{2}$	Lyra			30,29	45 $\frac{1}{2}$	37
	27 53	XX	30 28	α Aquilæ			30,305		
10	45 53	V 47 51—	49 47	Capella					
	50 18 $\frac{1}{2}$	51 42—	53 3 $\frac{1}{2}$	Rigel					
	11 19		14 1 $\frac{1}{2}$	ϵ Orionis					
11	46 25	VIII 47 47+	49 10 $\frac{1}{2}$	β Cancræ					
	15 26	IX 17 19+	19 14	α Cygni					
	24 53—	26 57 $\frac{1}{2}$	29 2	δ Ursæ majoris	3 15 $\frac{2}{3}$	3 3 14			
		31 25 $\frac{1}{2}$	33 26 $\frac{1}{2}$	α Ursæ majoris	4 9 c	4 3 7 —			
	58 30	59 53	1 15—	α Hydræ					
		X 50 41+	52 8 $\frac{1}{2}$	γ Leonis					
12	11 15—	O 12 37+	13 59+	} Sun	55 26 $\frac{2}{3}$	59 1 2 $\frac{1}{2}$	30,155	51 $\frac{1}{2}$	45
	13 24	14 47—	16 8—		54 54	58 4 8			
13	54 17 $\frac{1}{2}$	VII 55 54+	57 30 $\frac{1}{2}$	Castor					
	1 55—	VIII 3 17	4 39—	Procyon					
		7 12+	8 44 $\frac{1}{2}$	Pollux			29,85	52	44 $\frac{1}{2}$
18	9 36	O 10 57 $\frac{1}{2}$	12 19 $\frac{1}{2}$	} Sun	53 5—	56 4 15 $\frac{1}{2}$	30,175	53 $\frac{1}{2}$	45
	11 45	13 6+	14 28+		52 32 c	56 0 4 $\frac{3}{4}$			
	14 32 d	V 16 30	18 26	Capella					
	58 4 $\frac{1}{2}$	59 27	1 49	α Orionis	44 50 $\frac{1}{2}$	47 6 10 c			
	4 17 $\frac{1}{2}$	VI 5 46+	7 14+	Saturn	29 31—	30 3 14 —			

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
March 18	50 12+	VI 51 38—	53 2 $\frac{1}{2}$	Sirius	68 34 $\frac{1}{2}$	73 1 3 $\frac{2}{3}$	30,35	53 $\frac{1}{2}$	40 $\frac{1}{2}$
		VII 31 9	32 31+	β Ursa minoris					
	34 42 $\frac{1}{2}$	36 20—	37 55	Castor	19 49—	21 1 1 $\frac{2}{3}$	30,375	56	40
	42 20	43 42 $\frac{1}{2}$	45 4—	Procyon	46 23	49 3 13 c			
	46 4	47 37 $\frac{1}{2}$	49 10—	Pollux	23 37 $\frac{1}{3}$	25 1 9 —			
	48 1 $\frac{1}{2}$	VIII 49 55—	51 50—	α Cygni	83 12—	88 6 0 c			
	57 27 $\frac{1}{2}$	59 32 $\frac{1}{2}$	1 36	γ Ursa majoris	3 17	3 4 0 cW			
		IX 4 0—	6 1	α Ursa majoris	4 9 $\frac{1}{2}$	4 3 8+W			
	31 5+	32 28	33 50—	α Hydrae	59 0 $\frac{3}{4}$	63 6 11 c			
	9 22 $\frac{1}{2}$	X 10 48 $\frac{1}{2}$		η Leonis					
		12 9+	13 32	Regulus	39 6 c	41 5 10 $\frac{1}{2}$			
	18 22+	19 53—	21 22	ζ Leonis	27 37 $\frac{3}{4}$	29 3 12			
	21 48	23 16+	24 43	γ Leonis	31 11 $\frac{1}{4}$	33 2 2	30,4	53	39
		XX 47 52	49 46	α Cygni					
19	9 18—	O 10 41	12 2	} Sun	52 41+	56 1 9 c	30,305	55	44
	11 28	12 50	14 11		52 8 $\frac{1}{2}$	55 4 15			
	10 37	V 12 35	14 31	Capella					
		25 41	27 3	γ Orionis					
	54 9	55 31	57 53	α Orionis					
	0 32 $\frac{1}{2}$	VI 2 1	3 29	Saturn					
	30 47	VII 32 24	34 0+	Castor	19 49—	21 1 2 —			
	38 24	39 46	41 8 $\frac{1}{2}$	Procyon	46 23 c	49 3 13 c			
	42 9	43 42	45 14	Pollux					
21	38 26—	VI 39 51	41 16—	Sirius					
		VII 24 33	26 9	Castor					
	30 33+	31 56	33 17 $\frac{1}{2}$	Procyon					
	34 18	35 51 $\frac{1}{2}$	37 24	Pollux					
22	8 25	O 9 47		} Sun			30,34	48	40
	10 33 $\frac{1}{2}$	11 55 $\frac{1}{2}$	8 17						
	39 37	III 41 9	42 40	Moon First Limb					
		IV 25 23+	25 23+	Aldebaran					
	58 51+	V 0 49—	2 45	Capella					
	3 16		6 1	Rigel					
		13 55	15 17	γ Orionis					
		25 38 $\frac{1}{2}$		ϵ Orionis					
	42 23—	43 45 $\frac{1}{2}$	45 7 $\frac{1}{2}$	α Orionis					
	49 19	50 48—	52 15 $\frac{1}{2}$	Saturn			30,39	51	40
23	8 7	O 9 29 $\frac{1}{2}$	10 50 $\frac{1}{2}$	} Sun					
	10 16	11 38+	12 59 $\frac{1}{2}$				30,365	51 $\frac{1}{2}$	40 $\frac{1}{2}$
	28 24 $\frac{1}{2}$	VIII 30 18—	32 12	α Cygni					
	26 20 $\frac{1}{2}$	XX 28 16+	30 10	α Cygni					
25		O 8 53		} Sun			30,21	49 $\frac{1}{2}$	45
	9 39 $\frac{1}{2}$	11 1 $\frac{1}{2}$	12 23						
April 1	5 24	O 6 46+	8 8—	} Sun			30,225	48 $\frac{1}{2}$	47 $\frac{1}{2}$
	7 33	8 55	10 17—						
	19 37+	IV 21 35 $\frac{1}{2}$		Capella			30,2	50	46 $\frac{1}{2}$
		25 25+	26 47+	Rigel					
	3 9+	V 4 32—	5 53 $\frac{1}{2}$	α Orionis					
		13 51 $\frac{1}{2}$	15 18 $\frac{1}{2}$	Saturn					
	39 47	VI 41 24+	43 0 $\frac{1}{2}$	Castor					
	47 24 $\frac{1}{2}$	48 47	50 9	Procyon					
		52 42 $\frac{1}{2}$	54 14 $\frac{1}{2}$	Pollux					
	53 5 $\frac{1}{2}$	VII 54 59 $\frac{1}{2}$	56 54+	α Cygni					

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
April 1	17 45 $\frac{1}{2}$ 51 2 $\frac{1}{2}$	XVI 19 42— XIX 52 58	21 39 54 52—	Capella α Cygni			30,185 30,215	45 46	38 40
2	5 6— 7 14 $\frac{1}{2}$ 15 42— 8 42 $\frac{1}{2}$ 51 21 43 29 47 13+ 49 10 $\frac{1}{2}$ 47 7	o 6 28+ 8 37+ III 40 49 $\frac{1}{2}$ IV 17 40— V o 36 10 12— 52 47 VI 37 29— 44 52— 48 46 $\frac{1}{2}$ VII 51 4 XIX 49 2 $\frac{1}{2}$	7 50— 9 59— 42 14 19 35 $\frac{1}{2}$ 1 58 54 12 39 5— 46 13 50 19 52 59— 50 57—	} Sun Aldebaran Capella α Orionis Saturn Sirius Castor Procyon Pollux α Cygni α Cygni	6 27 $\frac{1}{3}$	6 7 2 c	30,17 30,13	50 $\frac{1}{2}$ 50 $\frac{1}{2}$	47 $\frac{1}{2}$ 45 $\frac{1}{2}$
3	4 47 $\frac{1}{2}$ 6 57	o 6 10 $\frac{1}{2}$ 8 19 $\frac{1}{2}$ VII 47 9+	7 32— 9 41+	} Sun α Cygni	46 50 $\frac{1}{2}$ 46 18 c	49 7 11 $\frac{1}{2}$ 49 3 1 $\frac{1}{2}$	30,01	52	51
4	4 30 $\frac{1}{2}$ 6 40— 35 39— 39 23	o 5 53 8 1 $\frac{1}{2}$ III 32 59 VI 29 38 $\frac{1}{2}$ 37 1 40 57—	7 14 9 24 34 24— 31 14 $\frac{1}{2}$ 38 23—	} Sun Aldebaran Castor Procyon Pollux	46 28 45 55 c 19 49+ 46 23 $\frac{1}{2}$	49 4 8 c 48 7 13 $\frac{1}{2}$ 21 1 2 49 3 13 $\frac{1}{2}$	29,8	50	46
5	4 14— 6 22+ 35 28	o 5 36— 7 45 VI 33 6 37 1 $\frac{1}{2}$	6 58— 9 6 34 27 $\frac{1}{2}$ 38 34—	} Sun Procyon Pollux	46 5 45 32 $\frac{2}{3}$ 23 37 $\frac{2}{3}$	49 1 4 $\frac{1}{2}$ 48 4 10 + 25 1 10 c	29,63	52 $\frac{1}{2}$	47
6	3 57— 6 6	o 5 20— 7 29—	6 41 $\frac{1}{2}$ 8 50 $\frac{1}{2}$	} Sun	45 42 $\frac{1}{3}$ 45 10 c	48 6 0 + 48 1 7 —	29,7	52	49 $\frac{1}{2}$
8	5 32 12 20 19 58— 23 42 8 43+	o 4 46 6 55+ VI 13 57 $\frac{1}{2}$ 21 20 $\frac{1}{2}$ 25 16— VIII 10 5 $\frac{1}{2}$	6 8+ 8 17 15 33 $\frac{1}{2}$ 22 42 26 48 11 27 $\frac{1}{2}$	} Sun U. L. Castor Procyon Pollux α Hydræ	44 25+ 44 25+ 47 3 1 c	47 3 1 c	29,81 29,87	47 $\frac{1}{2}$ 48	46 47 $\frac{2}{3}$
9	3 7 5 16	o 4 30 6 39	5 51 $\frac{1}{2}$ 8 0 $\frac{1}{2}$	} Sun	44 35+ 44 3 c	47 4 8 — 46 7 14 c	29,907	47	42
10	27 52 4 30 12 7 $\frac{1}{2}$ 15 52+	IV 29 15 VI 6 7 $\frac{1}{2}$ 13 30+ 17 25 $\frac{1}{2}$	30 36+ 7 44 14 52—	α Orionis Castor Procyon Pollux			29,97	50	45
11	2 35 $\frac{1}{2}$ 4 45	o 3 58+ 6 7 $\frac{1}{2}$	5 20 7 30	} Sun	43 51 43 18 $\frac{1}{3}$	46 6 3 $\frac{1}{3}$ 46 1 9 c			
16	7 26 $\frac{1}{2}$ 8 29 $\frac{1}{2}$	IX 11 31— 18 49 24 1	12 31 14 29	β Ursæ majoris α Ursæ majoris $\downarrow$ Ursæ majoris δ Leonis					
17	1 9+	o 4 42 $\frac{1}{2}$	3 55 $\frac{1}{2}$ 6 4+	} Sun			29,5	58	61

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
April 18	33 10— 40 47 44 31 9 12½ 15 42+ 16 50+	v 42 9½ 46 5 VIII 10 36½ 17 36+ 18 20 21 44½ IX 2 9½ 3 40+ 10 59— 16 11+ 16 29+ 44 23 51 34— 55 51 x 57 54½	43 31 12 0 19 29½ 19 49½ 23 11 4 41— 6 39 12 55 17 38½ 17 54 58 12+	Castor Procyon Pollux Regulus α Ursæ majoris ζ Leonis γ Leonis β Ursæ majoris α Ursæ majoris ↓ Ursæ majoris δ Leonis θ Leonis γ Cephei β Leonis γ Ursæ majoris ε Ursæ majoris			29,735	59	57
20	2 41 1 22+ 12 26+	o 4 5 VIII 2 46½ 13 54—	3 18— 5 28 4 10 15 21	} Sun Regulus γ Leonis	39 6	41 5 11 c	29,765	58	56½
21	o 19½ 2 30— 44 46 8 31½	o 3 54— III 46 9½ VII 58 52 VIII 9 59	3 7 5 16½ 47 31 o 15 11 25½	} Sun α Orionis Regulus γ Leonis	40 20 39 47½ 31 11½	43 o 3 c 42 3 9 c 33 2 2 +	29,485	60	63
22	2 18	o 3 43	2 54+ 5 6+	} Sun			29,465	59½	60
23	59 57 2 7+ 24 56½	o 3 31+ v 26 30+	2 44+ 4 55 28 2	} Sun Pollux	39 40½ 39 7¼	42 2 8 c 41 5 14½	29,51	60½	58
24	1 57	o 3 21½ VII 58 14	2 34 4 45 1 26 59 41	} Sun Moon's First Limb U.L. γ Leonis	39 20½ 38 48¼ 38 45½	41 7 12 41 3 2½ 41 2 12	29,5	59	56½
25	59 36 1 47— 33 14½	o 3 11½ VIII 34 44 36 15	2 24 4 35 37 15½ 39 13½	} Sun β Ursæ majoris α Ursæ majoris			29,578	57	56
26		III 26 34+		α Orionis					
27	59 17+ 1 29—	o o 42 2 53½	2 6 4 17	} Sun	38 22¾ 37 50½	40 7 8 — 40 2 14½	29,7	56½	53½
29	59 o+ 1 12+	o o 25½ 2 37½		} Sun	37 45 c 37 13¼	40 2 2 + 39 5 10 —	29,325	56	54
30	38 43	x 13 30 24 59— 25 3— x 40 6½		Polaris } Jupiter Spica Virginis	39 42½ 56 42— 62 7½	42 2 14 — 60 3 13 + 66 2 3 —			
May 2	58 40½ o 52	o o 5½	1 30— 3 41+	} Sun			29,87	53	53

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
May 2		IV 39 57 47 20—	48 41	Castor Procyon					
5	58 19+	XXIII 59 45+	1 10	} Sun	35 42 $\frac{1}{2}$	38 0 11 +	29,93	58	59
6	0 32+	O 1 58	3 23		35 10 $\frac{1}{3}$	37 4 1 $\frac{2}{3}$			
6	58 16	XXIII 59 42—	1 7	} Sun			29,91	58	58
7	0 29—	O 1 55—	3 19+						
	54 47 $\frac{1}{2}$	VI 56 12	57 35+	Regulus					
	5 51+	VII 7 19+	8 46	γ Leonis					
	21 11+	X 22 33		ζ Virginis					
	35 49			η Ursa majoris					
	41 47		44 40	η Bootis					
		XI 4 37 $\frac{1}{2}$	6 4—	Arcturus	31 48—	33 7 5 $\frac{1}{4}$			
	20 26 $\frac{1}{2}$		23 57	γ Bootis					
			35 50 $\frac{1}{2}$	ϵ Bootis					
	36 7		38 57 $\frac{1}{2}$	α Librae					
	45 39			β Ursa minoris	22 52 $\frac{3}{4}$	24 3 4			
	2 34—	XII 3 57	5 19 $\frac{1}{2}$	β Librae			29,97	61	53
			5 31	δ Bootis					
	21 40+		23 4—	δ Serpentis					
	22 39+		24 11	α Coronae					
	30 47+		25 42 $\frac{1}{2}$	α Serpentis					
			33 31 $\frac{1}{2}$	β Serpentis					
			34 47 $\frac{1}{2}$	ϵ Serpentis					
			38 34—	δ Scorpionis					
	44 29—		47 24 $\frac{1}{2}$	β Scorpionis					
	49 49—		52 41 $\frac{1}{2}$	Antares	78 2—	83 1 15	29,975	60	52
	12 56—	XIII 14 27	15 56 $\frac{1}{2}$						
7	58 13+	XXIII	1 4+	} Sun	35 10—	37 4 0 $\frac{2}{3}$	30,02	64	63 $\frac{1}{2}$
8	0 26+	O 1 52 $\frac{1}{2}$	3 17 $\frac{1}{2}$		34 37+	36 7 7—			
	54 41	I 56 39—	58 35	Capella					
	38 12	II 39 35	40 57	α Orionis					
	14 50	IV 16 27	18 3	Castor					
	22 27+		23 50+	Procyon					
	26 12		27 45 $\frac{1}{2}$	Pollux					
	50 53—	VI 52 17+	53 40 $\frac{2}{3}$	Regulus			30,025	68	66
	1 56 $\frac{1}{2}$	VII 3 24 $\frac{2}{3}$	4 51	γ Leonis					
	59 15 $\frac{1}{2}$	XI 0 43	2 9	Arcturus					
			18 18	γ Bootis					
	24 14		25 38 $\frac{1}{2}$	ζ Bootis					
	28 51		30 24	ϵ Bootis					
			33 39—	α Librae					
	41 44+		47 3	β Ursa minoris	22 52 $\frac{3}{4}$	24 3 4 c			
			48 41+	β Bootis					
	58 39	XII	1 24	β Librae					
8	58 11	XXIII 59 37	1 2	} Sun L. L.	34 53 $\frac{1}{3}$	37 1 12 —	30,135	65	66
9	0 24 $\frac{1}{2}$	O 1 50 $\frac{1}{2}$							
9	58 9	XXIII 59 36—		} Sun	34 38—	36 7 8 c	30,15	67	66
10	0 22 $\frac{1}{2}$	O 1 48 $\frac{1}{2}$	3 14+		34 6—	36 2 15 $\frac{2}{3}$			
	43 2		45 50 $\frac{1}{2}$	Regulus					
	54 6 $\frac{2}{3}$	VI 55 34 $\frac{1}{2}$	57 1 $\frac{1}{2}$	γ Leonis			30,1	68	63
	13 10	IX 15 32+	17 57—	α Cassiopeae					
	28 14 $\frac{1}{2}$			γ Cassiopeae					
	29 13 $\frac{1}{2}$			ϵ Ursa majoris					
				Polaris	39 42 $\frac{1}{3}$	42 2 14			
				} Jupiter	56 22—	60 0 15 $\frac{2}{3}$	30,1	65	55

Time by the Clock.

Day of the Month 1768.	First Wire.	Passage over Meridian.		Third Wire.	Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
						Deg.	Parts of 96			
May 10		X	0 57 $\frac{1}{2}$		Spica Virginis	62 7 $\frac{1}{2}$	66 2 3			
	51 25 $\frac{1}{2}$		52 53	54 19 $\frac{1}{2}$	Arcturus	31 48—	33 7 0 c			
10	58 8—	XXIII	59 34+		} Sun	34 38—	36 7 8 c	30,025	63	63
11		O	1 47	3 13		34 6—	36 2 15 $\frac{2}{3}$			
		IV	4 42	6 19—	Castor					
	10 42 $\frac{1}{2}$		12 5+	13 27—	Procyon			29,98	65	62
	14 27		16 0 $\frac{1}{2}$	17 33—	Pollux					
	39 8	VI	40 32 $\frac{1}{2}$	41 56	Regulus					
	50 11 $\frac{1}{2}$		51 40—	53 6 $\frac{1}{2}$	γ Leonis					
		VII	33 34 $\frac{1}{2}$	36 33 $\frac{1}{2}$	α Ursæ majoris	10 46 $\frac{2}{3}$	11 3 15 $\frac{1}{3}$			
			46 6 $\frac{1}{2}$	47 34	δ Leonis					
	20 4	VIII	21 29 $\frac{1}{2}$	22 53 $\frac{1}{2}$	β Leonis					
		IX	30 27		Polaris	39 42 $\frac{1}{3}$	42 2 13 $\frac{2}{3}$			
				39 27	} Jupiter					
				39 30		56 20—	60 0 11 $\frac{1}{2}$			
	55 39		57 2 $\frac{1}{3}$	58 25—	Spica Virginis	62 7 $\frac{1}{2}$	66 2 3 —			
		X	6 54—		ζ Virginis					
	26 7 $\frac{1}{2}$		27 34 $\frac{2}{3}$	29 1	η Bootis					
	47 30 $\frac{1}{2}$		48 58	50 24 $\frac{1}{2}$	Arcturus	31 48—	33 7 5 $\frac{2}{3}$			
14	27 23 $\frac{1}{2}$	VI	28 48+	30 11 $\frac{1}{2}$	Regulus			30,11	57	
	35 46+	X	37 13 $\frac{2}{3}$	38 40+	Arcturus	31 47 $\frac{3}{4}$	33 7 5 $\frac{1}{3}$	30,13	55	46
14	58 9+	XXIII	59 37—	1 2+	} Sun	33 24 $\frac{1}{2}$	35 5 1 $\frac{1}{3}$	30,15	56 $\frac{1}{2}$	54
15	1 23 $\frac{1}{2}$	O	1 50 $\frac{1}{2}$	3 16 $\frac{1}{2}$		32 52 $\frac{1}{4}$	35 0 7 $\frac{1}{3}$			
	49 52 $\frac{1}{2}$	IX	51 15	52 36+	ζ Virginis					
	10 28 $\frac{1}{2}$	X	11 55 $\frac{1}{2}$	13 21 $\frac{1}{2}$	η Bootis					
			33 19	34 45+	Arcturus	31 48—	33 7 6			
	49 8—		50 54+	52 39	γ Bootis					
	56 50—		58 14 $\frac{1}{2}$	59 39—	ζ Bootis					
	1 27+	XI	3 0	4 32	ϵ Bootis					
			6 15	7 39—	α Libræ			30,13	58	
17	32 10 $\frac{1}{4}$	IX	33 33 $\frac{1}{2}$	34 56	Spica	62 7 $\frac{1}{2}$	66 2 3			
	42 3		43 25	44 45 $\frac{1}{2}$	ζ Virginis					
	2 39 $\frac{1}{4}$	X	4 6		η Bootis					
20	20 24 d	IX	21 49 $\frac{1}{4}$	23 11 $\frac{1}{2}$	Spica	62 7+	66 2 3			
	30 18 $\frac{1}{2}$		31 41		ζ Virginis					
	50 54 $\frac{3}{4}$		52 22	53 48	η Bootis					
	12 17 $\frac{3}{4}$	X		15 11 $\frac{1}{2}$	Arcturus	31 47 $\frac{1}{2}$	33 7 4 $\frac{3}{4}$ d			
20	58 28	XXIII	59 56 $\frac{1}{2}$	1 23 $\frac{1}{2}$	} Sun			29,94	63	59
21	0 45	O	2 12 $\frac{1}{4}$	3 39						
23	58 40 $\frac{1}{4}$	O	0 8	1 34 $\frac{3}{4}$	} Sun			30,23	67 $\frac{1}{2}$	67
	0 55 $\frac{1}{4}$		2 23	3 50 $\frac{1}{4}$						
24	58 46	O	0 14	1 41	} Sun			30,165	68 $\frac{1}{2}$	67
	1 2		2 30	3 57						
	4 46	IX	6 9 $\frac{1}{2}$	7 32	Spica					
	14 39		16 1	17 22	ζ Virginis					
	35 15		36 42	38 8	η Bootis					
25	58 52 $\frac{1}{2}$	O	0 20	1 47 $\frac{1}{2}$	} Sun			30,07	69	64
	1 9		2 36 $\frac{1}{2}$	4 4						
27	59 5	O	0 35	2 2	} Sun			30	63 $\frac{3}{4}$	57
	1 22		2 50	4 16 $\frac{1}{2}$ d						

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	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
May 28	1 30	o 3 o	2 11 4 27	} Sun			29,735	66 $\frac{1}{2}$	63 $\frac{1}{2}$
31	59 40 $\frac{1}{2}$	o 3 25 d	2 37 $\frac{1}{2}$ 4 54 $\frac{1}{2}$	} Sun			29,515	65 $\frac{1}{2}$	62
	37 21	viii 38 44 $\frac{3}{4}$	40 7	Spica					
	29 14	ix 30 41 $\frac{1}{2}$	32 7 $\frac{1}{2}$	Arcturus					
		x 3 36 $\frac{1}{2}$	5 0+	α Libræ					
		18 40	20 28	β Bootis					
	28 37 $\frac{1}{4}$	30 0 $\frac{1}{4}$	31 22	β Libræ					
	48 42 $\frac{1}{2}$	50 15	51 46 $\frac{1}{2}$	α Coronæ					
	56 51	58 13 $\frac{1}{2}$	59 35	α Serpentis					
		xi 0 50 $\frac{1}{4}$	2 15 $\frac{1}{4}$	β Serpentis					
	3 15	4 37	5 58 $\frac{1}{2}$	ϵ Serpentis					
		12 0	13 27 $\frac{1}{4}$	δ Scorpionis					
	15 52	17 19	18 44 $\frac{1}{2}$	β Scorpionis					
	26 8	27 30	28 51 $\frac{1}{4}$	δ Ophiuci					
	29 59	31 20 $\frac{1}{2}$	32 42	ϵ Ophiuci					
	38 58 $\frac{1}{4}$	40 29 $\frac{1}{2}$	41 59 $\frac{3}{4}$	Antares					
June 1	59 51	o 1 20	2 47	} Sun			29,815	66 $\frac{3}{4}$	63 $\frac{1}{2}$
	2 7	3 36	5 4						
2	0 0 $\frac{1}{2}$	o 1 29 $\frac{1}{2}$	2 57	} Sun			30,65	64 $\frac{1}{4}$	62 $\frac{1}{2}$
	2 17 $\frac{1}{2}$	3 46 $\frac{1}{2}$	5 14 $\frac{1}{4}$						
		ix 22 51+	24 18	Arcturus					
	50 59 $\frac{1}{2}$	52 32	54 4	ϵ Bootis					
			52 10 $\frac{1}{2}$	α Libræ					
7	0 56 $\frac{3}{4}$	o 2 25 $\frac{3}{4}$	3 54	} Sun			29,74	72 $\frac{1}{2}$	72 $\frac{1}{2}$
	3 13 $\frac{3}{4}$								
10	1 33 d	3 3	4 31	} Sun	29 23—	31 2 11 c	29,43	65	64
	3 50 $\frac{1}{2}$	5 20 $\frac{1}{4}$	6 48		28 51—	30 6 2 c			
15		4 10—	5 37 $\frac{3}{4}$ d	} Sun			29,53	58	60
	4 57 $\frac{1}{2}$	viii 10 32 $\frac{3}{4}$	11 59	η Bootis					
	9 6	31 56+	33 23	Arcturus	31 48 $\frac{1}{3}$	33 7 6 $\frac{1}{3}$			
	30 29	49 31	51 16	γ Bootis					
	0 4 $\frac{1}{2}$	ix 1 37	3 9 $\frac{1}{2}$	ϵ Bootis					
		19 55	21 43	β Bootis					
	29 53	31 15	32 37 $\frac{1}{2}$	β Libræ					
	49 58	51 30	53 1 $\frac{1}{2}$	α Coronæ					
	58 6	59 29	0 50 $\frac{1}{2}$	α Serpentis	45 2	48 0 5	29,7	58	51
		x 2 6	3 30 $\frac{1}{2}$	β Serpentis					
	4 30	5 52 $\frac{1}{2}$	7 14	ϵ Serpentis					
	17 8	18 34 $\frac{1}{2}$	20 0 $\frac{1}{2}$	β Scorpionis					
16	5 11 d	o 4 23 d	5 51	} Sun	29 4 $\frac{1}{3}$	31 0 1	29,77	60 $\frac{1}{2}$	60
		6 41—	8 10—		28 32 $\frac{1}{4}$	30 3 8			
	5 11	viii 6 38	8 4	η Bootis			29,785	62	57
	26 34	28 1 $\frac{1}{2}$	29 28	Arcturus	31 48 $\frac{1}{4}$	33 7 6 $\frac{1}{3}$			
	43 50 $\frac{1}{2}$	45 36 $\frac{1}{2}$	47 21	γ Bootis					
	51 32	52 57	53 21	ζ Bootis					
	56 9	57 42 $\frac{1}{2}$	59 14+	ϵ Bootis					
17		o 4 37	6 6—	} Sun	29 2 $\frac{2}{3}$	30 7 13 $\frac{1}{3}$	29,695	63	65
	5 25	6 55	8 23		28 30 $\frac{2}{3}$	30 3 5 c			
	22 39	viii 24 6	25 34	Arcturus	31 48 $\frac{1}{3}$	33 7 6 $\frac{2}{3}$	29,64	64 $\frac{1}{2}$	61

ASTRONOMICAL OBSERVATIONS.

25

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
June 19	3 35 $\frac{2}{3}$ 5 53 d 14 49	o 5 4 $\frac{1}{2}$ VIII 16 16 $\frac{1}{2}$		} Sun Arcturus	29 1 28 29	30 7 9 + 30 3 1 d	29,9	65 $\frac{1}{2}$	65
20	3 48 $\frac{1}{2}$ 19 2 7 48 20 40	o VII 20 25 + X 9 11 22 11	9 4 $\frac{3}{4}$ 21 48 10 32 23 41	} Sun L. L. Spica Virginis δ Ophiuci Antares	29 0 $\frac{1}{2}$	30 7 8 c	29,71	63 $\frac{1}{2}$	61
21	6 21 38 0 + 6 59 - 6 23 26 28 34 36 $\frac{1}{4}$ 41 0 $\frac{1}{2}$ 53 38 3 54 7 45 16 45 21 46 33 53 0 32 $\frac{1}{2}$ 5 33 25 44 $\frac{1}{2}$ 51 45 29 58 -	o 5 32 $\frac{1}{2}$ 7 50 - d V 39 25 - VII 16 30 $\frac{1}{2}$ VIII 8 26 + IX 7 46 + 28 0 $\frac{3}{4}$ 35 59 $\frac{1}{4}$ 38 36 $\frac{1}{4}$ 42 23 55 4 X 5 16 9 6 $\frac{1}{2}$ 18 15 $\frac{1}{2}$ 23 14 $\frac{1}{2}$ XI 2 28 $\frac{3}{4}$ 6 57 $\frac{1}{4}$ 27 59 $\frac{1}{2}$ 53 57 XII 31 43	7 1 9 19 40 48 + 17 53 9 53 10 58 + 29 32 37 20 $\frac{1}{2}$ 40 1 43 44 $\frac{1}{4}$ 56 30 $\frac{3}{4}$ 6 37 10 28 19 46 37 5 $\frac{1}{2}$ 4 26 $\frac{1}{4}$ 8 21 30 13 - 56 8 33 26 +	} Sun Moon's First Limb U. L. Spica Virginis Arcturus β Libræ δ Bootis α Coronæ α Serpentis β Serpentis ε Serpentis β Scorpionis δ Ophiuci ε Ophiuci Antares β Herculis ζ Herculis Capella α Herculis β Draconis γ Draconis Lyra	29 0 + 28 28 55 40 + 31 48	30 7 7 + 30 2 14 + 59 3 1 33 7 6 c	29,99 30,04	62 63 $\frac{1}{2}$	56 $\frac{1}{2}$
22	3 4 - 1 37 + 21 50 47 50	VIII 4 31 + XI 3 2 $\frac{1}{2}$ 24 4 $\frac{1}{2}$ 50 1 +	5 57 $\frac{1}{2}$ 26 18 52 11 $\frac{1}{2}$	Arcturus α Hercules β Draconis γ Draconis	o 16 c o 41 $\frac{1}{3}$	o 2 5 - W o 5 14 c W			
23		X 59 7 XI 20 9	o 31 22 22	α Herculis β Draconis					
24	4 44 7 2 53 47 14 0 - 40 0 18 12 $\frac{1}{4}$	o 6 14 8 32 X 6 30 + XI 16 14 42 11 $\frac{1}{4}$ XII 19 58	7 42 10 0 8 0 56 36 - 18 27 44 22 21 41 $\frac{1}{4}$	} Sun Antares α Herculis β Draconis γ Draconis Lyra	o 16 $\frac{1}{2}$ o 41 c 13 37 $\frac{1}{4}$	o 2 5 $\frac{1}{2}$ E o 5 13 c E 14 4 3 $\frac{1}{2}$ E	30,123 30,45	67 $\frac{1}{2}$ 65	64 $\frac{1}{4}$ 60
25	10 4 $\frac{1}{2}$ 36 5 14 17 $\frac{1}{2}$	XI 12 19 $\frac{1}{2}$ 38 16 XII 16 3 -	14 32 + 40 26 $\frac{1}{2}$ 17 46	β Draconis γ Draconis Lyra	o 16 $\frac{1}{4}$ o 41 $\frac{1}{3}$ 13 37 $\frac{1}{4}$	o 2 5 c W o 5 14 c W 14 4 4 $\frac{1}{2}$ W	29,51	65	61 $\frac{1}{2}$
26	32 9 10 22	XI 34 21 XII 12 7 $\frac{1}{2}$	36 32 13 51 +	γ Draconis Lyra	o 41 $\frac{1}{3}$ 13 38 -	o 5 14 - Wa 14 4 5 - Wa	29,565	65	61
29	5 50 - 8 7	o 7 19 + 9 37 -	8 46 $\frac{1}{2}$	} Sun	29 14 $\frac{2}{3}$ 28 42 $\frac{2}{3}$	31 1 8 $\frac{1}{2}$ d 30 5 0 c	29,8	67 $\frac{1}{2}$	65

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
June 30	50 28 $\frac{3}{4}$ 16 29 54 42	x 52 45 xi 18 41 56 27	54 56 $\frac{1}{4}$ 20 51 58 11	β Draconis γ Draconis Lyra	13 37+	14 4 3+ E	29,93	68	60
July 1	6 14 $\frac{1}{2}$ 47 17	o 7 44 $\frac{1}{2}$ 10 1 $\frac{1}{2}$ viii 48 49 $\frac{1}{2}$	11 29 $\frac{1}{2}$ 50 21 $\frac{1}{4}$	} Sun α Coronæ	28 50 $\frac{3}{4}$	31 2 10 + 30 6 2 +	29,8	72	74 $\frac{1}{2}$
2	6 27 8 45— 43 22 $\frac{1}{2}$ 51 30 $\frac{1}{2}$ 5 12 $\frac{1}{4}$ 10 32 $\frac{1}{2}$ 20 48 $\frac{1}{2}$ 24 39 33 39 38 41 15 30 $\frac{1}{2}$ 17 27 $\frac{1}{2}$ 22 27 42 30 $\frac{1}{2}$ 50 21 $\frac{1}{2}$ 54 36 $\frac{1}{2}$ 8 40— 46 52 $\frac{1}{2}$ 58 54 $\frac{1}{2}$ 12 50 15 25 $\frac{1}{2}$	o 7 56+ 10 14+ viii 44 54 $\frac{1}{2}$ 52 53 $\frac{1}{4}$ 55 31 59 17 ix 6 41 12 0— 22 10 26 1 $\frac{1}{2}$ 31 37 35 10 $\frac{1}{2}$ 40 9 $\frac{1}{2}$ x 16 55 $\frac{1}{2}$ 19 24+ 23 52 43 54 $\frac{1}{2}$ 44 53 $\frac{1}{2}$ 51 44 $\frac{1}{2}$ 55 59 57 4 $\frac{1}{2}$ xi 10 51 48 37 $\frac{1}{2}$ xii 0 26 xxii 17 23	9 25— 11 42+ 46 26 54 15 56 55 $\frac{1}{2}$ o 39 13 25 23 31 $\frac{1}{2}$ 27 22 $\frac{1}{2}$ 33 3 $\frac{1}{2}$ 36 40 $\frac{1}{2}$ 41 37 21 21 $\frac{1}{4}$ 25 15 $\frac{1}{2}$ 53 5 $\frac{1}{2}$ 58 36 $\frac{1}{4}$ 13 1 $\frac{1}{2}$ 50 21 1 56 $\frac{1}{2}$ 15 37 $\frac{1}{2}$ 19 19 $\frac{1}{2}$	} Sun α Coronæ α Serpentis β Serpentis ϵ Serpentis δ Scorpionis β Scorpionis δ Ophiuci ϵ Ophiuci γ Herculis Antares β Herculis η Ophiuci Capella α Herculis α Ophiuci β Draconis β Ophiuci γ Ophiuci μ Herculis γ Draconis Lyra σ Sagittarii ζ Aquilæ Capella	29 27 28 55 78 2 $\frac{1}{4}$ 81 57 $\frac{1}{4}$ o 16+ o 2 5—W o 41 $\frac{1}{3}$ 13 38 c o 5 14—W 14 4 5+W 31 48 o 16 $\frac{3}{4}$ o 40 $\frac{1}{2}$ 13 37 29 55 $\frac{1}{2}$ 29 23 $\frac{2}{3}$ 29 30 $\frac{1}{2}$ 81 57 c	31 3 5 a 30 6 12 c 83 1 15 c 87 3 6 + o 2 5—W o 5 14—W 14 4 5+W 33 7 6 c o 2 6 $\frac{1}{4}$ E o 5 12+ E 14 4 3 $\frac{1}{3}$ E 31 7 5 $\frac{1}{2}$ 31 2 13 + 32 0 5 $\frac{1}{3}$ d 31 3 13 c 87 3 5 $\frac{1}{2}$ a	29,65 29,725 29,705 29,66 29,285 29,74 29,85	72 69 $\frac{1}{2}$ 68 $\frac{1}{2}$ 70 67 68 68	73 $\frac{1}{2}$ 59 60 $\frac{1}{2}$ 68 66 65 64
3	19 58 38 44 46 27 $\frac{1}{4}$ 51 37 4 44 42 57 $\frac{3}{4}$	vii 21 25 $\frac{1}{2}$ x 40 59 47 49 $\frac{1}{2}$ 53 9 $\frac{1}{2}$ xi 6 56 $\frac{1}{4}$ 44 42 $\frac{1}{2}$	22 52 17 26 43 12 49 11 54 41 $\frac{1}{4}$ 9 6 $\frac{3}{4}$ 46 26	Arcturus Capella β Draconis β Ophiuci γ Ophiuci γ Draconis Lyra	31 48 o 16 $\frac{3}{4}$ o 40 $\frac{1}{2}$ 13 37	33 7 6 c o 2 6 $\frac{1}{4}$ E o 5 12+ E 14 4 3 $\frac{1}{3}$ E	29,695	68	60
7	7 25 9 42	o 8 54 11 11	10 22 12 39	} Sun	29 55 $\frac{1}{2}$ 29 23 $\frac{2}{3}$	31 7 5 $\frac{1}{2}$ 31 2 13 +	29,285	67	66
8	7 36 19 53 $\frac{1}{4}$ 28 2 47 4 57 20 1 10 54 o $\frac{1}{2}$ d 33 51 $\frac{1}{2}$	o 11 21 $\frac{3}{4}$ viii 21 26 $\frac{1}{2}$ 29 25 $\frac{1}{2}$ 43 12 $\frac{1}{4}$ 48 31 58 42 $\frac{1}{2}$ ix 2 33 16 41 55 55 $\frac{1}{2}$ ix 8 51 $\frac{1}{2}$ 35 14 $\frac{1}{2}$	10 33 12 50 22 58 30 47 44 40 49 57 $\frac{1}{4}$ o 4 $\frac{1}{2}$ 3 54 18 8 $\frac{1}{4}$ 57 53 $\frac{3}{4}$ 10 19 36 37	} Sun α Coronæ α Serpentis δ Scorpionis β Scorpionis δ Ophiuci ϵ Ophiuci β Herculis Capella β Herculis α Herculis	29 30 $\frac{1}{2}$ 81 57 c	32 0 5 $\frac{1}{3}$ d 31 3 13 c 87 3 5 $\frac{1}{2}$ a	29,74 29,85	68 68	65 64
10	33 51 $\frac{1}{2}$	ix 8 51 $\frac{1}{2}$ 35 14 $\frac{1}{2}$	10 19 36 37	β Herculis α Herculis					

Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
July 10	38 20	IX 39 56	41 31	ϵ Herculis					
		45 38	47 12	η Ophiuci					
	51 9 $\frac{1}{2}$	52 34	53 58	α Herculis					
	11 21			β Draconis					
	19 5			β Ophiuci					
	37 22	29 34	41 44	γ Draconis	0 41 $\frac{1}{2}$	0 5 13 $\frac{2}{3}$ W	29,85	68	63 $\frac{3}{4}$
11	8 6	O 9 34 $\frac{1}{2}$	11 2	} Sun	30 25 c	32 3 9 c	29,85	69	66
	10 23		13 19		29 53 $\frac{1}{2}$	31 7 1 $\frac{2}{3}$			
13	55 39	VIII 57 7 $\frac{1}{2}$	58 35	β Herculis					
	22 7	IX 23 30 $\frac{1}{2}$	24 52 $\frac{1}{2}$	α Herculis					
	26 36	28 11 $\frac{1}{2}$	29 47	ϵ Herculis					
	34 25 $\frac{1}{4}$		38 20	Capella					
		40 49 $\frac{3}{4}$	42 14	α Herculis					
	59 37	X 1 52	4 5	β Draconis	0 17 c	0 2 7-E a			
	7 20	8 42 $\frac{1}{2}$	10 4	β Ophiuci					
	25 37 $\frac{1}{2}$	27 49	30 0 $\frac{1}{4}$	γ Draconis	0 40 $\frac{1}{2}$	0 5 12 c Ea	29,75	67	63
	3 50 $\frac{1}{2}$	5 35 $\frac{1}{2}$	7 19 $\frac{1}{2}$	Lyra	13 37—	14 4 3 $\frac{1}{3}$ Ea			
15	26 36	XI 28 32 $\frac{1}{2}$	30 30	Capella	81 57	87 3 6 d	29,84	67	61
17	8 52	O 10 19 d	11 48	} Sun	31 21 $\frac{1}{2}$	33 3 9 d	29,73	67	65
		12 34 d	14 4		30 49 $\frac{1}{2}$	32 7 0+ d			
	44 41	VII 46 13 $\frac{1}{2}$	47 45	α Coronæ					
	18 47	IX 20 43	22 41	Capella	81 57 c	87 3 5 $\frac{3}{4}$ a	29,755	66	61 $\frac{1}{2}$
	23 46	25 11	26 34 $\frac{1}{2}$	α Herculis					
	43 58	46 12 $\frac{1}{2}$	48 26	β Draconis	0 17 c	0 2 6 $\frac{3}{4}$ Ea			
	51 41	53 3 $\frac{1}{4}$	54 24 $\frac{1}{2}$	β Ophiuci					
	55 55 $\frac{1}{4}$	57 17	58 39	γ Ophiuci					
	9 58 $\frac{1}{2}$	X 12 10 $\frac{1}{4}$	14 20 $\frac{1}{4}$	γ Draconis	0 40 $\frac{1}{2}$	0 5 12 c Ea			
	48 11	49 56	51 40	Lyra	13 38 c	14 4 5 c Wa			
	0 14	XI 1 45	3 16	σ Sagittarii					
		11 37 $\frac{1}{2}$	13 5	$\circ$ Sagittarii					
	15 19 $\frac{3}{4}$		18 15	π Sagittarii	72 31 $\frac{1}{2}$	78 3 7 $\frac{1}{3}$ d			
	33 11 $\frac{1}{4}$	34 33 $\frac{1}{2}$	35 54 $\frac{1}{4}$	δ Aquilæ					
	40 33	42 5 $\frac{1}{2}$	43 37	β Cygni	24 42 $\frac{1}{2}$	26 2 13 $\frac{1}{2}$			
	54 32 $\frac{1}{4}$	55 55 $\frac{1}{4}$	57 18	γ Aquilæ					
	58 46	XII 0 9	1 30 $\frac{1}{2}$	α Aquilæ	43 55 c	46 6 12+ a	29,74	65	59 $\frac{1}{2}$
	3 13 $\frac{1}{4}$	4 35 $\frac{1}{4}$	5 57	β Aquilæ					
19	9 4	O	11 58	} Sun	31 43 c	33 6 10 c	29,475	66 $\frac{1}{2}$	64
	11 19				31 11+	32 2 2 c			
20	9 7	O 10 36—	12 1	} Sun d					
	11 24—	12 50+	14 17 $\frac{1}{2}$						
	23 13 $\frac{1}{4}$	VIII 24 44 $\frac{1}{4}$	26 14 $\frac{1}{2}$	Antares	78 2+	83 1 15 +	29,845	68	63
	7 2 $\frac{1}{2}$	IX 8 58 $\frac{1}{2}$	10 56 $\frac{1}{2}$	Capella	81 57 c	87 3 6 c			
	12 1	13 25 $\frac{3}{4}$	14 49 $\frac{1}{2}$	α Herculis					
	32 12 $\frac{1}{4}$	34 27 $\frac{3}{4}$	36 40 $\frac{1}{4}$	β Draconis	0 16+	0 2 5 c W			
	39 56	41 18 $\frac{1}{2}$	42 39 $\frac{1}{2}$	β Ophiuci					
	44 10 $\frac{1}{2}$	45 33	46 53 $\frac{3}{4}$	γ Ophiuci					
	58 13	X 0 25	2 35 $\frac{1}{4}$	γ Draconis	0 41+	0 5 14-Wa			
	21 21	22 52	24 21	λ Sagittarii					
	36 26 $\frac{1}{4}$	38 11 $\frac{1}{4}$	39 55 $\frac{1}{4}$	Lyra	13 37+	14 4 3 $\frac{1}{4}$ E			
	48 28 $\frac{1}{2}$	50 1	51 31	σ Sagittarii	78 41 $\frac{2}{3}$	83 7 9 c			
	58 24 $\frac{1}{4}$	59 53	1 20	$\circ$ Sagittarii	74 12 $\frac{2}{3}$	79 1 5 +			
	3 35	XI 5 3	6 30	π Sagittarii	73 31 $\frac{1}{2}$	78 3 7 +			
	21 27	22 49	24 10	δ Aquilæ					

Time by the Clock.

Time by the Clock.											
Day of the Month 1768.	First Wire.	Passage over			Third Wire.	Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
		Meridian.					Deg.	Parts of 96			
July 20	28 48 $\frac{1}{4}$	XI	30 21	31 52	β Cygni	24 42 $\frac{2}{3}$	26 2 14 —	29,875	65	60	
	42 47 $\frac{3}{4}$		44 11	45 33	γ Aquilæ						
	47 1 $\frac{1}{4}$		48 24 $\frac{1}{4}$	49 45	α Aquilæ	43 55 c	46 6 12				
	51 34		52 51	54 12	β Aquilæ						
		XXI	6 58		Capella						
21	9 13		10 40 $\frac{3}{4}$	12 7	} Sun	32 6 c	34 1 14 $\frac{2}{3}$	30	68 $\frac{1}{2}$	65 $\frac{1}{2}$	
	11 28		12 55 $\frac{3}{4}$			31 34 c	33 5 5 $\frac{2}{3}$				
24		O	10 50	12 16	} Sun			29,815	75	74 $\frac{3}{4}$	
	11 37 $\frac{1}{2}$			13 4 $\frac{1}{2}$			14 30 $\frac{1}{2}$				
25	9 25	O	10 51 $\frac{1}{2}$	12 18—	} Sun			29,71	75 $\frac{1}{2}$	78	
	11 39			13 6			14 33				
26	41 33	XX	43 30	45 26	Capella			29,945	72	71 $\frac{1}{2}$	
27		VII		58 53	Antares			30,01	73	69	
	39 39 $\frac{3}{4}$	VIII	41 35 $\frac{1}{2}$	43 33 $\frac{1}{2}$	Capella	81 57 $\frac{1}{4}$	87 3 6 c				
			46 3	47 27	α Herculis						
	4 50	IX	7 5	9 18	β Draconis	0 17 c	0 2 7—E a				
	16 48	XX	39 35 $\frac{1}{2}$	41 32	γ Ophiuci			30,06	73	72 $\frac{1}{2}$	
			XXII		16 5	Capella					
28	9 27	O	10 54	12 19 $\frac{1}{2}$	} Sun	33 37 c	35 6 14 c a	30,07	75 $\frac{3}{4}$	78	
	11 41			13 7		14 34	33 5 c				35 2 5 c a
		VIII	37 41 $\frac{1}{4}$	39 38 $\frac{1}{2}$	Capella						
			42 8	43 32	α Herculis						
	0 55 $\frac{1}{4}$	IX	3 10 $\frac{1}{4}$	5 23 $\frac{1}{4}$	β Draconis	0 16 $\frac{1}{4}$	0 2 5+W	30,03	74 $\frac{1}{2}$	70 $\frac{1}{2}$	
	8 38 $\frac{1}{2}$			10 1	11 22	β Ophiuci					
	12 53		14 15	15 36 $\frac{1}{4}$	γ Ophiuci						
	26 55 $\frac{1}{2}$	X	29 7 $\frac{1}{2}$	31 17 $\frac{1}{2}$	γ Draconis	0 40 $\frac{1}{2}$	0 5 12 c E	30,01	73 $\frac{1}{2}$	68 $\frac{1}{2}$	
	5 8 $\frac{3}{4}$			6 53 $\frac{1}{2}$	8 38	Lyra	13 37 c				14 4 3+Ea
	31 6		32 31	33 54 $\frac{1}{4}$	ζ Aquilæ						
	50 9		51 31 $\frac{1}{2}$	52 52 $\frac{1}{4}$	δ Aquilæ						
	57 30 $\frac{3}{4}$	XI	59 3	0 34 $\frac{1}{4}$	β Cygni	24 40 $\frac{2}{3}$	26 2 13 $\frac{1}{2}$ d	29,845	76	77	
	11 30			12 53 $\frac{1}{2}$	14 15 $\frac{3}{4}$	γ Aquilæ					
	15 43 $\frac{1}{2}$			17 6 $\frac{1}{2}$	18 28 $\frac{1}{2}$	α Aquilæ	43 55 c				46 6 12 $\frac{1}{2}$ d
29		O	10 52	12 18	} Sun			29,845	76	77	
	11 40			13 6		14 32					
Aug. 1		IX	13 27	15 38	γ Draconis			29,7	67 $\frac{1}{2}$	68	
2		O	12 57	14 22	} Sun			29,625	66 $\frac{1}{2}$	62	
	16 10			18 5 $\frac{1}{2}$		20 3					
		VIII	22 33 $\frac{1}{2}$	23 57 $\frac{1}{4}$	Capella						
	41 20		43 35	45 48 $\frac{1}{4}$	α Herculis						
		IX	9 32 $\frac{1}{4}$	11 43	β Draconis			29,595	67 $\frac{1}{3}$	62	
				47 19	49 3	γ Draconis					
	45 34		12 56 $\frac{1}{4}$	18 2 $\frac{1}{2}$	Lyra	13 37+	14 4 3 $\frac{1}{3}$ Ea				
	11 31 $\frac{1}{2}$	XX	16 6 $\frac{1}{4}$	0 24	ζ Aquilæ			29,63	69 $\frac{1}{3}$	67	
	14 8 $\frac{1}{2}$			59 2	52 36	Capella					
		XXI			α Orionis						
3	9 15	O	10 40	12 5	} Sun	35 7 $\frac{1}{2}$	37 3 11 $\frac{1}{4}$ a	29,63	69 $\frac{1}{3}$	67	
	11 28 $\frac{1}{2}$			12 54 $\frac{1}{2}$		14 19 $\frac{1}{2}$	34 35+				36 7 3 c a

ASTRONOMICAL OBSERVATIONS.

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Day of the Month 1768.	Time by the Clock.			Object.	Obs. Zenith Dist. in		Barometer.	Thermom. within.	Thermom. without.
	First Wire.	Passage over Meridian.	Third Wire.		Deg.	Parts of 96			
Aug. 3	28 27	VII 29 58 $\frac{1}{2}$	31 28	Antares					
	12 16 $\frac{1}{4}$	VIII 14 12 $\frac{1}{4}$	16 10 $\frac{1}{4}$	Capella	81 57 +	87 3 6 +	29,72	68 $\frac{1}{2}$	66
		18 39 d		α Herculis					
		50 45 $\frac{1}{2}$	52 7	γ Ophiuci					
	3 26	IX 5 38	7 48	γ Draconis	0 41 -	0 5 13 + W			
	41 39 $\frac{1}{2}$	43 24	45 8 $\frac{1}{2}$	Lyra	13 37 c	14 4 3 +			
		X	37 5	β Cygni					
	48 I			γ Aquilæ					
	52 14 $\frac{1}{4}$		54 59 $\frac{1}{4}$	α Aquilæ			29,72	67 $\frac{1}{2}$	65
	10 14	XX 12 12 -	14 8	Capella					
	4 9 11	O 10 37	12 3	} Sun			29,8	70	68
	11 23	12 50	14 15 -						
	14 45 +	V 16 12 $\frac{1}{2}$	17 39	Arcturus					
	33 31	VIII 35 45 $\frac{1}{2}$	37 58 $\frac{1}{2}$	β Draconis	0 17 -	0 2 6 $\frac{2}{3}$ E			
	41 14	42 36 $\frac{1}{2}$	43 58	β Ophiuci					
4	45 29	46 50 $\frac{3}{4}$	48 12	γ Ophiuci					
	59 31	IX I 43	3 53 $\frac{1}{4}$	γ Draconis	0 40 $\frac{1}{2}$	0 5 12 c E			
	37 45	39 29 $\frac{1}{2}$	41 13 $\frac{1}{4}$	Lyra	13 37	14 4 3 $\frac{1}{3}$	29,85	70	66 $\frac{1}{2}$
	3 42 $\frac{1}{4}$	X 5 6 $\frac{3}{4}$	6 30	ζ Aquilæ					
	22 45	24 7 $\frac{1}{2}$	25 28 $\frac{1}{4}$	δ Aquilæ					
	30 6 $\frac{1}{4}$	31 39	33 10	β Cygni	24 42 $\frac{2}{3}$	26 2 14 -			
	44 5 $\frac{3}{4}$	45 29	46 51 $\frac{1}{2}$	γ Aquilæ					
	48 19 $\frac{1}{4}$	49 42 $\frac{1}{2}$	51 4 $\frac{1}{2}$	α Aquilæ	43 55 c	46 6 12 $\frac{1}{2}$	29,87	69	66
	5 9 6	O 10 31 d	14 9	} Sun					
	4 26 $\frac{1}{2}$	VIII 6 22 $\frac{1}{2}$	8 20	Capella	81 57 +	87 3 6 +	29,94	72	69
	9 24	10 49 $\frac{1}{4}$	12 13	α Herculis					
	29 35 $\frac{3}{4}$	31 51	34 3 $\frac{3}{4}$	β Draconis	0 16 $\frac{1}{2}$	0 2 5 $\frac{2}{3}$ W			
	37 19 $\frac{1}{4}$	38 41 $\frac{1}{2}$	40 3	β Ophiuci					
	41 34	42 56	44 17 $\frac{1}{4}$	γ Ophiuci					
5	55 36 $\frac{1}{4}$	57 48 $\frac{1}{2}$	59 58 $\frac{3}{4}$	γ Draconis	0 41	0 5 13 W			
	33 49 $\frac{3}{4}$	IX 35 35	37 18 $\frac{3}{4}$	Lyra	13 37 c	14 4 3 c a	29,93	70 $\frac{1}{4}$	68
	59 47 $\frac{1}{2}$	X I 12	2 35	ζ Aquilæ					
	18 50 $\frac{1}{2}$	20 12 $\frac{1}{4}$	21 34	δ Aquilæ					
	26 11 $\frac{1}{2}$	27 44	29 15	β Cygni	24 42 $\frac{1}{2}$	26 2 13 $\frac{1}{3}$			
	40 11	41 34 $\frac{1}{4}$	42 56 $\frac{3}{4}$	γ Aquilæ					
	44 25	45 48	47 10	α Aquilæ	44 55 c	46 6 12 + a	29,93	70 $\frac{3}{4}$	68
	48 52	50 14 $\frac{1}{2}$	51 36	β Aquilæ					

Day of the Month & Object. 1767.	Number of the wire.	Transits by Reflection.		Day of the Month & Object. 1767.	Number of the wire.	Transits by Reflection.	
		Manner of Observing.	Time by the Clock.			Manner of Observing.	Time by the Clock.
July 15 <i>Lyra</i>	1	directly	x 53 56	Aug. 1 <i>Lyra</i>	1	directly	IX 47 19
	2	by floating Glafs	55 43 $\frac{1}{2}$		2	by Quickfilver	49 3
	3	directly	57 25		3	directly	50 47
16 <i>α Ophiuci</i>	1	directly	IX 45 37		1	directly	IX 43 23
	2	by Quickfilver	47 1		2	by Water	45 6
	3	directly	48 25		3	directly	46 52
16 <i>Lyra</i>	1	directly	x 50 0		1	directly	VIII 13 15
	2	by Water	51 44		2	by Quickfilver	14 58
	3	directly	53 29		3	directly	16 43 $\frac{3}{4}$
17 <i>Sun</i>	1	{ directly	0 5 59 $\frac{1}{2}$	25 <i>α Aquilæ</i>	1	directly	IX 23 48 $\frac{1}{4}$
	2	{ directly	5 12		2	by Water	25 11
	3	{ by Water	7 25		3	directly	26 33 $\frac{1}{2}$
	3	{ directly	6 39		1	{ by Water	0 0 3
	3	{ by Water	8 54		2	{ directly	0 2 14 $\frac{1}{4}$
19 <i>Sun</i>	1	{ directly	0 3 55		3	{ directly	1 27 $\frac{1}{2}$
	2	{ directly	6 10		3	{ directly	3 37 $\frac{1}{2}$
	3	{ by Water	5 23		3	{ directly	2 50 $\frac{3}{4}$
	3	{ by Water	7 38		3	{ by Water	5 0
	3	{ directly	6 49 $\frac{1}{2}$		1	{ directly	0 1 58
	3	{ by Water	9 5		2	{ directly	1 13
24 <i>Lyra</i>	1	directly	x 18 39		3	{ directly	3 21
	2	by Water	20 23		3	{ directly	2 34
	3	directly	22 7 $\frac{1}{2}$		3	{ by Quickfilver	4 44
25 <i>α Aquilæ</i>	1	directly	XI 25 18	Sept. 23 <i>Sun</i>	1	{ directly	XXIII 51 11
	2	by Quickfilver	26 40		2	{ directly	53 20
	3	directly	28 1 $\frac{1}{2}$		3	{ by Water	52 33
26 <i>Lyra</i>	1	directly	x 10 49		3	{ by Water	54 41
	2	by Quickfilver	12 34		3	{ by Water	54 54
	3	directly	14 16 $\frac{1}{2}$		3	{ directly	56 8

Corresponding Altitudes.

Sun Sept. 21, 1767.

Azimuth 65° Parts of 96
Zenith Dist. $70 \ 32\frac{1}{2}$ or $75 \ 2 \ 0$

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st wire	VII 56 { 53 57	III 51 { 33 30	XI 54 13 13 $\frac{1}{2}$
2 ^d	59 { 21 25	49 { 5 2	13 13 $\frac{1}{2}$
1 st	VIII 0 { 45 48		
3 ^d	1 { 40 43		
2 ^d	3 { 14 17	45 { 13 11	13 $\frac{1}{2}$ 14
3 ^d	5 { 33 $\frac{1}{2}$ 36	42 { 49	12 $\frac{1}{2}$

Mean h / XI 54 13 $\frac{1}{2}$
Corⁿ. for the $\frac{1}{2}$ interval 4 c +23 $\frac{1}{4}$
Passage over true Meridian XI 54 36 $\frac{1}{2}$
Passage by transit Telescope XI 54 37 $\frac{1}{2}$

Sun second set Sept. 21, 1767.

Azimuth 63° Parts of 96
Zenith Dist. $68 \ 26$ or $73 \ 0 \ 0$

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st	VIII 12 { 18 20	III 36 { 8 6	XI 54 13 13
2 ^d	14 { 50 53	33 { 36 33	13 13
1 st	16 { 17 19	32 { 11 8	14 13 $\frac{1}{2}$
3 ^d	17 { 13 16	30 { 13 11	13 13 $\frac{1}{2}$
2 ^d	18 { 50 53	29 { 37 34	13 $\frac{1}{2}$ 13 $\frac{1}{2}$
3 ^d	21 { 15 17	27 { 13 11	14 14

Mean h / XI 54 13 $\frac{1}{2}$
Corⁿ. for the $\frac{1}{2}$ interval 3 40 +22 $\frac{1}{2}$
Passage over true Meridian XI 54 36
Passage by transit Telescope XI 54 37 $\frac{1}{2}$

Aldebaran Nov. 27, 1767.

Azimuth $65\frac{1}{2}^{\circ}$ Parts of 96
Zenith Dist. $52 \ 44$ or $56 \ 2 \ 0$

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st	VIII 40 50 $\frac{1}{2}$	XIV 16 1 $\frac{1}{4}$	XI 58 25 $\frac{7}{8}$
2 ^d	43 16 $\frac{1}{4}$	13 35 $\frac{1}{4}$	25 $\frac{3}{4}$
3 ^d	45 33 $\frac{1}{4}$	11 18	25 $\frac{5}{8}$

Passage over true Meridian XI 58 25 $\frac{3}{4}$
Passage by transit Telescope XI 58 29

Corresponding Altitudes.

γ *Tauri* Nov. 27, 1767.

Zenith Distance as before

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st wire	VIII 30 35 $\frac{3}{4}$	XIV 54 19 $\frac{1}{2}$	XI 42 27 $\frac{5}{8}$
2 ^d	33 3 $\frac{1}{4}$	51 51	27 $\frac{1}{8}$
3 ^d	35 23 $\frac{1}{2}$	49 31 $\frac{1}{4}$	27 $\frac{3}{8}$

Passage over true Meridian XI 42 27 $\frac{3}{8}$
Passage by transit Telescope XI 42 31

ϵ *Tauri* Nov. 27, 1767.

Zenith Distance as before

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st	VIII 18 40 $\frac{1}{2}$	XV 23 10 $\frac{3}{4}$	XI 50 55 $\frac{3}{8}$
2 ^d	21 0	80 50 $\frac{3}{4}$	55 $\frac{3}{8}$
3 ^d	23 12	18 38 $\frac{1}{4}$	55 $\frac{1}{8}$

Passage over true Meridian XI 50 55 $\frac{3}{8}$
Passage by transit Telescope XI 50 58

Sun Nov. 28, 1767.

Azimuth 35° Parts of 96
Zenith Dist. $81 \ 12\frac{1}{2}$ or $86 \ 5 \ 0$

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st	IX 4 { 52 57	II 36 { 7 2	XI 50 29 $\frac{1}{2}$ 29 $\frac{1}{2}$
2 ^d	8 { 28 37	32 { 28 23	28 25
1 st	10 { 38 43	30 { 20 14	29 28 $\frac{1}{2}$
3 ^d	{ 11 56 12 2	28 { 58 54	27 28
2 ^d	14 { 23 29	26 { 35 29	29 29
3 ^d	{ 17 59 18 4	22 { 59 55	29 29 $\frac{1}{2}$

Mean h / XI 50 28 $\frac{1}{2}$
Corⁿ. for the $\frac{1}{2}$ interval 2 40 +11 $\frac{1}{2}$
Passage over true Meridian XI 50 40
Passage by transit Telescope XI 50 45 $\frac{5}{8}$

δ *Cassiopeæ* Nov. 28, 1767.

Zenith Dist. 26° Parts of 96
or $27 \ 5 \ 13$

Time by the Clock.

	Eastern Az.	Western Az.	Meridian.
1 st	V 39 10 $\frac{1}{2}$	XI 47 14	VIII 43 12 $\frac{1}{4}$
2 ^d	41 49 $\frac{1}{2}$	44 36 $\frac{1}{2}$	13
3 ^d	44 18	42 7	12 $\frac{1}{2}$

Passage over true Meridian VIII 43 12 $\frac{7}{12}$
Passage by transit Telescope VII 43 13 $\frac{1}{2}$

Corresponding Altitudes.		
<i>ε Cassiopeæ</i> Nov. 28, 1767.		
Zenith Distance as before		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VI 5 12 $\frac{1}{2}$	XII 15 22	IX 10 17 $\frac{1}{4}$
2 ^d 8 8 $\frac{1}{2}$	12 27	17 $\frac{3}{4}$
3 ^d 10 55	9 40	17 $\frac{1}{2}$
Passage over true Meridian		IX 10 17 $\frac{1}{2}$
Passage by transit Telescope		IX 10 16 $\frac{1}{2}$
<i>Sun</i> March 3, 1767.		
Azimuth 56° 5' 0" Parts of 96		
Zenith Dist. 74 31 or 79 3 15		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VIII 34 18-	III 58 5 $\frac{1}{2}$	XII 16 11 $\frac{3}{4}$
2 ^d 36 56 $\frac{1}{2}$	55 27	11 $\frac{3}{4}$
1 st 38 29	53 54	11 $\frac{1}{2}$
3 ^d 39 26	52 57	11 $\frac{1}{2}$
2 ^d 41 9	51 12	10 $\frac{1}{2}$
3 ^d 43 41	48 41 $\frac{1}{2}$	11 $\frac{1}{4}$
Mean h 1		XII 16 11 $\frac{3}{8}$
Cor ⁿ . for the $\frac{1}{2}$ interval 3 40		-22 $\frac{3}{4}$
Passage over true Meridian		XII 15 48 $\frac{5}{8}$
Passage by transit Telescope		XII 15 53
<i>γ Leonis</i> March 5, 1768.		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VII 23 26	XV 4 52	XI 14 9
2 ^d 25 43-	2 35 $\frac{1}{2}$	9 $\frac{1}{8}$
3 ^d 27 51	0 27 $\frac{1}{2}$	9 $\frac{1}{4}$
Passage over true Meridian		XI 14 9 $\frac{1}{8}$
Passage by transit Telescope		XI 14 13
<i>η Leonis</i> March 5, 1768.		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VII 29 45 $\frac{1}{2}$	XIV 33 37	I 41 $\frac{1}{4}$
3 ^d 31 58	31 25 $\frac{1}{2}$	41 $\frac{3}{4}$
Passage over true Meridian		XI 1 41 $\frac{1}{2}$
Passage by transit Telescope		XI 1 45

Corresponding Altitudes.		
<i>Regulus</i> March 5, 1768.		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VII 56 28+	XIV 9 34 $\frac{1}{2}$	3 1 $\frac{1}{4}$
2 ^d 59 1+	7 4	3 2 $\frac{1}{2}$
3 ^d VIII 1 23 $\frac{1}{2}$	4 41	3 2 $\frac{3}{4}$
Passage over true Meridian		XI 3 2
Passage by transit Telescope		XI 3 6-
<i>Sun</i> April 22, 1768.		
Azimuth 74° 0' 1" Parts of 96		
Zenith Dist. 62 30 or 66 5 5 $\frac{1}{2}$		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VII 55 8-	IV 10 37 $\frac{1}{2}$	XII 2 52 $\frac{5}{8}$
2 ^d 57 24+	8 20+	52 $\frac{1}{4}$
1 st 58 44 $\frac{1}{2}$	7 1-	52 $\frac{5}{8}$
3 ^d 59 34	6 10+	52 $\frac{1}{8}$
2 ^d VIII 1 1	4 44-	52 $\frac{3}{8}$
3 ^d 3 11+	2 33 $\frac{1}{2}$	52 $\frac{3}{8}$
Mean		XII 2 52,39
<i>Sun</i> second set April 22, 1768.		
Azimuth 71° 0' 1" Parts of 96		
Zenith Dist. 60 42 or 64 6 0		
Time by the Clock.		
Eastern Az.	Western Az.	Meridian.
VIII 7 22	III 58 23	XII 2 52 $\frac{1}{2}$
2 ^d 9 40+	56 5	52 $\frac{5}{8}$
1 st 11 1+	54 44	52 $\frac{5}{8}$
3 ^d 11 51 $\frac{1}{2}$	53 53	52 $\frac{1}{4}$
2 ^d 13 20 $\frac{1}{2}$	52 25 $\frac{1}{2}$	53
3 ^d 15 33	50 10 $\frac{1}{2}$	51 $\frac{3}{4}$
Mean		XII 2 52,45
Mean of both sets h 1		XII 2 52,42
Cor ⁿ . for the $\frac{1}{2}$ interval 4 0		18,32
Passage over true Meridian		XII 2 34,1
Passage by transit Telescope		XII 2 37 $\frac{3}{8}$

As the morning and afternoon Altitudes of the Sun must be taken on the same day; in the date, and in numbering the hours, the Civil not the Astronomical account is followed.

In some of the observations of the sun, two numbers are found against every wire; one is the time of the appulse of the limb to the first edge of the wire, the other is the time of the emergence from behind the wire.

In computing the passage over the true meridian, $\frac{1}{4}$ of a second is allowed for each + or - in the observed time of the corresponding Altitudes,

Distances of the Moon from the Sun & Stars, taken with an Hadley's Quadrant.

Day of the Month, &c. 1767.	Time by the Clock.	Diff. of $\odot$ from $\ast$	Zenith Distances.	Day of the Month, &c. 1767.	Time by the Clock.	Diff. of $\odot$ from $\ast$	Zenith Distances.
Sept. 29	VI 38 0	40 55 $\frac{1}{2}$		Nov. 28			<i>Dup. limb</i>
$\odot$ Western limb	40 0	54 $\frac{1}{2}$		$\odot$ Western limb	II 52 0	86 55	70 58
β Capricorni	41 30	54 $\frac{1}{2}$		$\odot$ Eastern limb	55 0	57	70 37
	43 10	56			58 30	58	70 14
	47 0	52		Index Error } -4 $\frac{3}{4}$	III 4 30	87 1	69 35
Index Error } -2 $\frac{1}{2}$	VII 10 0	50 $\frac{1}{2}$			7 0	2	69 17 $\frac{1}{2}$
* Oct. 4	14 30	42		1768.	0 9 50	73 44	
		37	<i>low. limb</i>	April 22	13 10	46	
$\odot$ Western limb	VII 4 5	64 22		$\odot$ Western limb	16 10	48	
α Arietis	14 0	18		$\odot$ Eastern limb	20 50	50	
Index Error } -1 $\frac{1}{2}$	XII 27 40	61 42	72 10	Index Error } +1	23 50	51 $\frac{1}{2}$	
	33 28	39	72 48		26 50	52 $\frac{1}{2}$	
Oct. 4			β Capric.	April 23			<i>low. limb</i>
$\odot$ Western limb	VII 36 20	29 45	67 46	$\odot$ Western limb	VII 58 10	56 31 $\frac{1}{2}$	40 36
β Capricorni	VIII 38 20	30 12	69 56	Aldebaran	VIII 7 30	35+	41 36
Index Error } -1 $\frac{1}{2}$	50 30	18	70 39		15 30	38-	42 21
† Oct. 9			<i>low. limb</i>		20 30	40-	42 54 $\frac{1}{2}$
$\odot$ Eastern limb	X 9 35	20 31	52 2	Index Error } +1	24 30	42 $\frac{1}{2}$	43 21
Aldebaran	15 40	27 $\frac{1}{2}$	51 9		28 40	43 $\frac{1}{2}$	
	21 10	26	50 21		33 0	45	44 20
	38 52	18+	47 51	April 23			<i>low. limb</i>
	44 4	17	47 7	$\odot$ Western limb	VIII 46 5	23 13	45 55 $\frac{1}{2}$
	50 29	15	46 15	Regulus	50 0	13	
Index Error } -3	57 49	11 $\frac{1}{2}$	45 15		52 30	11	
	XI 1 10	10	44 48 $\frac{1}{4}$		55 0	10	47 2
Oct. 11			<i>Dup. limb</i>		59 30	9-	47 37
$\odot$ Eastern limb	XXII 21 10	116 10	72 21 $\frac{1}{2}$	IX 13 0	4	49 23	
$\odot$ Western limb	25 40	4	72 59		17 0	3	49 55
	29 20	4	73 30	Index Error } +1	19 0	2-	50 11
	33 50	2	74 6		22 0	0+	50 36
Index Error } -3	37 30	115 58 $\frac{1}{2}$	74 37	April 25			<i>Dup. limb</i>
	42 30	58	75 18	$\odot$ Western limb	IX 14 25	40 3	47 36
				Pollux	19 10	5	47 59
				Index Error } +1	28 40	9	48 48
				April 25			<i>low. limb</i>
* To this days Obs. add				$\odot$ Western limb	IX 45 45	51 41	50 54 $\frac{1}{2}$
Time by the Clock.	Z. Dist. <i>Dup. limb</i>	Time by the Clock.	Z. Dist. <i>Aldebar.</i>	Spica Virginis	X 11 20	31	53 37
VII 4 5	67 44 $\frac{1}{2}$	X 12 0	68 6		15 20	28	54 8 $\frac{1}{2}$
16 28	66 40	17 45	67 13		18 55	28	54 29
39 12	64 54	23 5	66 24	Index Error } +1	22 10	27	54 52 $\frac{1}{2}$
VIII 40 7	61 43	40 52	63 41		30 0	25	55 48 $\frac{1}{2}$
52 6	61 23	45 50	62 56 $\frac{1}{4}$				
		52 35	61 55				
	α Arietis	59 10	60 55 $\frac{1}{2}$				
VII 6 50	71 53	XI 2 45	60 22 $\frac{3}{4}$				
14 0	70 48						

The Zenith distances here set down, are not to be relied on to a minute; but are sufficient for computing the effect of parallax and refraction on the distances observed by the Hadley's Quadrant.

Other Observations made with the Hadley's Quadrant.

Day of the Month 1767.	Time by the Clock.			Day of the Month 1768.	Time by the Clock.		
Aug. 28	ix 30	Distance of Lyra & Arcturus	58 59 $\frac{1}{2}$	Feb. 4	viii 10	Distance Capella & Rigel repeated	54 16 $\frac{1}{2}$
		repeated	58 59 $\frac{1}{2}$		ix 30	Moon's Diam. Quad. arch on arch of excess	34 26
		again	58 57			Index er. from coincidence of the Moon's image	- 5
		Dist. of Lyra & α Aquilæ	34 15	5	viii 6	Distance Capella & Rigel	54 16 $\frac{1}{2}$
		Dist. Arcturus & α Aquilæ	81 10			Index error by Rigel	- 4 $\frac{1}{4}$
		Sun's Diameter taken on the Quadrantal arch	35	6	o 30	Sun's Diam. on Quad. arch on arch of excess	36 $\frac{1}{2}$ 27 $\frac{3}{4}$
Sept. 17		On the arch of excess	30			Sum of the Meridian Altitude of the Sun's lower limb and its depression when reflected by Water	87 51
		Sun's Diam. on Quad. arch on arch of excess	35 30	Apr. 5		Sun's Diam. on Quad. arch on arch of excess	31 $\frac{1}{2}$ 33-
Oct. 4	xxi 55	Index error from coincidence of direct and reflected image of Chesterton steeple	- 2			Note. The Horizon-glass rectified since Feb. 6	
		Sun's Diam. on Quad. arch on arch of excess	33 30			Meridian Altitude & depression Sun's upper limb	91 8 $\frac{1}{2}$
		Repeated on Quad. arch on arch of excess	33 $\frac{1}{2}$ 30+	8		Sun's Diam. on Quad. arch on arch of excess	32 34
9	ix 30	Index error by Aldebaran	- 3			Index er. by Chesterton ft.	+ 1 $\frac{1}{2}$
		Moon's Diam. Quad. arch on arch of excess	35 29			Meridian Altitude & depression Sun's upper limb	91 54
11	xxiii 30	Index er. by Chesterton ft.	- 3	9		Sun's Diam. on Quad. arch on arch of excess	31 $\frac{1}{2}$ 33 $\frac{2}{3}$
		Sun's Diam. on Quad. arch on arch of excess	36 29 $\frac{1}{2}$	21	xxii	Repeated on Quad. arch on arch of excess	31+ 33
		Repeated on Quad. arch on arch of excess	34 29			Sun's Diam. on Quad. arch on arch of excess	31 32 $\frac{1}{2}$
24	vi 15	Dist. of Lyra & Arcturus	58 58	22	i o	Meridian Altitude & depression Sun's lower limb	100 40-
		Index error by Capella	- 3			Sun's Diam. on Quad. arch on arch of excess	32- 33
Nov. 27	xxiii	Index er. by Chesterton ft. again	- 3 $\frac{1}{2}$ - 4	23		Repeated on Quad. arch on arch of excess	31 $\frac{1}{2}$ 33 $\frac{1}{2}$
		Sun's Diam. Quad. arch on arch of excess	37 27			Index er. by Chesterton ft. second time	+ 2 + 1
		Repeated on Quad. arch on arch of excess	36 $\frac{1}{2}$ 27	24		third	+ 1
30	xxii 13	Distance of Venus from the Sun's western limb	46 19			Meridian Altitude & depression Sun's lower limb	101 19
		again	46 19 $\frac{1}{2}$			Index er. by Chesterton ft.	+ 1 $\frac{1}{2}$
Dec. 1	o 50	again	46 21	Aug. 13	v	Sun's Diam. on Quad. arch on arch of excess	30+ 33 $\frac{1}{2}$
		Sun's Diam. on Quad. arch on arch of excess	37 27 $\frac{1}{2}$			Index er. by Chesterton ft.	+ 1 $\frac{2}{3}$
1768.		Index error	- 5			Dist. of Lyra & Arcturus	58 56
Jan. 19	viii 45	Distance Capella & Rigel	54 16 $\frac{1}{4}$		viii 42	repeated	58 57-
	ix 15	Distance Capella & Rigel	54 16 $\frac{3}{4}$		44	again	58 56
	ix 40	Index er. by Chesterton ft. again	- 4 - 4 $\frac{1}{2}$		51	again	58 56
	xxiii	Sun's Diam. on Quad. arch on arch of excess	37 28		54	again	58 56
23	o 35	Index error by Sirius	- 5		57	again	58 56
		by α Orionis	- 5	ix 16		Sum of Alt. & Depress. of Arcturus when reflected by Quicksilver	57 44
26	vii 15	Dist. of Capella & Rigel	54 17+			Dist. Arcturus & α Aquilæ	81 7
		Sun's Diam. on Quad. arch on arch of excess	37 28 $\frac{1}{2}$		29 $\frac{1}{2}$	repeated	81 7
		Index er. from coincidence of the Sun's image	- 4 $\frac{1}{2}$		35	Dist. of Lyra & α Aquilæ	34 9+
		Index er. by Chesterton ft. second time	- 3 - 4		43	repeated	34 9 $\frac{1}{4}$
		third	- 4		45	Index error by α Aquilæ	+ 2
Feb. 4	vii 20	Index error by Rigel	- 4 $\frac{1}{4}$	x o			

A Table for converting Ninetyfixth Parts of the Quadrant and their Subdivisions into Degrees, Minutes, and Seconds.

Pts	o	'	"	Pts	o	'	"	pts of vern. Subdivis.			pts of vern. Subdivis.				pts of vern. Subdivis.				
1	0	56	15	49	45	56	15	0	1	0	26,37	3	1	21	31,99	6	1	42	37,62
2	1	52	30	50	46	52	30	2	0	52,73		2	21	58,35		2	43	3,98	
3	2	48	45	51	47	48	45	3	1	19,10		3	22	24,72		3	43	30,35	
4	3	45	0	52	48	45	0	4	1	45,47		4	22	51,09		4	43	56,72	
5	4	41	15	53	49	41	15	5	2	11,84		5	23	17,46		5	44	23,09	
6	5	37	30	54	50	37	30	6	2	38,20		6	23	43,82		6	44	49,45	
7	6	33	45	55	51	33	45	7	3	4,57		7	24	10,19		7	45	15,82	
8	7	30	0	56	52	30	0	8	3	30,94		8	24	36,56		8	45	42,19	
9	8	26	15	57	53	26	15	9	3	57,30		9	25	2,92		9	46	8,55	
10	9	22	30	58	54	22	30	10	4	23,67		10	25	29,29		10	46	34,82	
11	10	18	45	59	55	18	45	11	4	50,04		11	25	55,66		11	47	1,29	
12	11	15	0	60	56	15	0	12	5	16,41		12	26	22,03		12	47	27,66	
13	12	11	15	61	57	11	15	13	5	42,77		13	26	48,39		13	47	54,02	
14	13	7	30	62	58	7	30	14	6	9,14		14	27	14,76		14	48	20,39	
15	14	3	45	63	59	3	45	15	6	35,51		15	27	41,13		15	48	46,76	
16	15	0	0	64	60	0	0	1	0	7,87		4	0	28,7,50		7	0	49,13,12	
17	15	56	15	65	60	56	15	1	1	28,24		1	28	33,87		1	49	39,49	
18	16	52	30	66	61	52	30	2	7	54,60		2	29	0,23		2	50	5,85	
19	17	48	45	67	62	48	45	3	8	20,97		3	29	26,60		3	50	32,22	
20	18	45	0	68	63	45	0	4	8	47,34		4	29	52,97		4	50	58,59	
21	19	41	15	69	64	41	15	5	9	13,71		5	30	19,34		5	51	24,96	
22	20	37	30	70	65	37	30	6	9	40,07		6	30	45,70		6	51	51,32	
23	21	33	45	71	66	33	45	7	10	6,44		7	31	12,07		7	52	17,69	
24	22	30	0	72	67	30	0	8	10	32,81		8	31	38,44		8	52	44,06	
25	23	26	15	73	68	26	15	9	10	59,17		9	32	4,80		9	53	10,42	
26	24	22	30	74	69	22	30	10	11	25,54		10	32	31,17		10	53	36,79	
27	25	18	45	75	70	18	45	11	11	51,91		11	32	57,54		11	54	3,16	
28	26	15	0	76	71	15	0	12	12	18,28		12	33	23,91		12	54	29,53	
29	27	11	15	77	72	11	15	13	12	44,64		13	33	50,27		13	54	55,89	
30	28	7	30	78	73	7	30	14	13	11,01		14	34	16,64		14	55	22,26	
31	29	3	45	79	74	3	45	15	13	37,38		15	34	43,01		15	55	48,63	
32	30	0	0	80	75	0	0	2	0	14,3,75		5	0	35,9,37		8	0	56,15	
33	30	56	15	81	75	56	15	1	14	30,12		1	35	35,74		1/4	0	6,59	
34	31	52	30	82	76	52	30	2	14	56,48		2	36	2,10		1/2	0	13,18	
35	32	48	45	83	77	48	45	3	15	22,85		3	36	28,47		3/4	0	19,77	
36	33	45	0	84	78	45	0	4	15	49,22		4	36	54,84		1	0	8,79	
37	34	41	15	85	79	41	15	5	16	15,59		5	37	21,21		2	0	17,58	
38	35	37	30	86	80	37	30	6	16	41,95		6	37	47,57		1	0	5,27	
39	36	33	45	87	81	33	45	7	17	8,32		7	38	13,94		2	0	10,55	
40	37	30	0	88	82	30	0	8	17	34,69		8	38	40,31		3	0	15,82	
41	38	26	15	89	83	26	15	9	18	1,05		9	39	6,67		4	0	21,09	
42	39	22	30	90	84	22	30	10	18	27,42		10	39	33,04		1	0	4,39	
43	40	18	45	91	85	18	45	11	18	53,79		11	39	59,41					
44	41	15	0	92	86	15	0	12	19	20,16		12	40	25,78					
45	42	11	15	93	87	11	15	13	19	46,52		13	40	52,14					
46	43	7	30	94	88	7	30	14	20	12,89		14	41	18,51					
47	44	3	45	95	89	3	45	15	20	39,26		15	41	44,88					
48	45	0	0	96	90	0	0	3	0	21,5,62		6	0	42,11,25		1/6	0	4,39	

The above Table was computed by Dr. Blisf.

R E M A R K S

ON THE FOREGOING

O B S E R V A T I O N S.

IN order to judge how far these observations may be relied on, it will be necessary to give some account of the instruments they were made with; and the methods used to fix and rectify those instruments.

1. The clock was made by *Shelton*, with a grid-iron pendulum, and beats dead seconds. It was fixed in the following manner.

Two pieces of oak ($5\frac{1}{2}$ inches broad, 3 thick and 24 long) were fixed to the wall of the observatory, by screwed bolts passing quite through it. The upper of these pieces, crossed the case of the clock, just above the *rising-board*,* the lower just above the bottom of the door of the case. The back of the case was screwed to these transverse pieces, by screws 0,4 inches diameter, and 3 inches long, which (having square heads) were forced by a long *spanner*, so as to cut their own threads quite through the oak. As the back of the case is a single board only half an inch thick, and the *frame-plates* on which the pendulum hangs, are fastened to it, to strengthen that part, a mahogany board an inch thick, and 6 inches wide, was put cross the back (but not glued to it) just above the rising-board, and the screws before mentioned, passing through the mahogany board, pinch the whole back between that board and the upper oak piece.† Nor does the clock stand upon the floor, but on a stone lying on the arch described in paragraph 6, and consequently is not liable to be disturbed by treading on the floor.

2. In the following register of the going of the clock, the first column contains the day of observation; the second, the error of the clock or its difference from mean time found by transits of the sun; the third, the time gained or

* The board on which the wheel-work stands.

† It would be better to suspend the pendulum directly upon the oak piece, or upon the wall itself. There would then be no necessity to fasten the case so strongly; as its motion would not then affect the pendulum; the wheel-work might be removed in order to be cleaned, without taking down the pendulum, which commonly alters the rate of the going of the clock, and it takes long time to re-adjust it.

or lost by the clock, being the differences of the numbers in the second column; the fourth, the same collected from transits of the fixed stars; the fifth, the number of days between the times of observation; the sixth, the mean rate of the clock for that interval, by the stars, found by dividing the numbers in the fourth column, by the corresponding ones in the fifth; the seventh column is the state of the thermometer, within doors, and without, for each day, at noon.

3. In making up the second column, the equation of time was taken from the Nautical Ephemeris. In strictness, the numbers in the second column should be corrected on account of the error in the position of the transit telescope, by the table paragraph 15, but the differences of those numbers, set down in the third column, would be so little affected by this correction that it may be omitted.

4. In computing the errors of the clock from transits of the stars, the apparent acceleration of one star was seldom the same with that of any other star observed on the same two nights, the difference amounting to one or two, rarely to three seconds; this difference arises from the error of the observer, and therefore the mean of the accelerations of five or six stars was taken for their common acceleration, which gives us the error of the clock. Every number in the fourth column, is the difference between this mean and what the clock ought to have shown it, according to the table given by M. De la Lande, in page 80, of the *Connoissance des mouvemens Celestes*.* No error in the position of the transit telescope can affect the numbers in this column, provided that position is not changed.

* In strictness, the numbers in the third column show what the clock has gained in so many real solar days; those in the fourth column, show what it has gained in as many sidereal days; therefore to make an accurate comparison of the gain of the clock, as shown by the sun, with its gain as shown by the stars, the numbers in the 4th column should be increased, in the ratio of the time between the transits of the sun on the days specified in the first column, to the time between the transits of the stars on the same days, or nearly in the ratio of a mean solar to a sidereal day; but this increase is so small it may be neglected.

Register

Register of the Clock in the Observatory.

Days of Obfer- vation.	Error by Sun too fast.	Gain by Sun.	Gain by Stars.	Number of Days.	Rate by Stars.	Ther- mometer		Days of Obfer- vation.	Error by Sun too fast.	Gain by Sun.	Gain by Stars.	Number of Days.	Rate by Stars.	Ther- mometer	
						within.	without.								
1767.	"	"	"	"	"			1768.	"	"	"	"	"		
July 11	39,5							Jan. 26	3 11					53 $\frac{1}{2}$	44
24	49,	9,5	9,35	13	0,72			Feb. 5	3 19,5	7,5	8,5	10	0,85	50	37 $\frac{1}{2}$
Aug. 4	57,75	8,75	10,1	11	0,92			21	3 35,	15,5	16,2	16	1,125	54 $\frac{1}{2}$	51
15	1 6,5	8,75	8,6	11	0,78	65		Mar. 3	3 46	11,0	11,6	11	1,054	51	36
25	1 15,25	8,75	8,7	10	0,87	65		18	3 57,5	11,5	12,5	15	0,833	53 $\frac{1}{2}$	45
Sep. 10	1 28	12,75	13,0	16	0,81	62		April 2	4 6,	8,5	8,7	15	0,58	50 $\frac{1}{2}$	47 $\frac{1}{2}$
21	1 37,5	9,5	8,6	11	0,78	63		18	4 18,5	12,5	13,6	16	0,85	59	57
Oct. 4	1 47,5	10,0	11,1	13	0,77	55		May 2	4 31,5	13,0	13,7	14	0,98	53	53
9	1 50,75	3,25	4,4	5	0,88	53	47	8	4 38	6,5	5,8	6	0,95	64	63
24	2 0,5	9,75	8,0	15	0,53	63	59	11	4 40,5	2,5	2,9	3	0,966	63	63
Nov. 14	2 16,25	15,75	18,05	21	0,86	52	47	24	4 55,4	14,9	14,75	13	1,13	68 $\frac{1}{2}$	67
28	2 26,62	10,37	10,06	14	0,72	56	45	31	5 0,1	05,6	6,8	7	0,97	65	62
Dec. 9	2 36,5	9,88	10,6	11	0,96	58	48	June 15	5 16	15,	14,75	15	0,98	58	60
17	2 44,75	8,25	8,4	8	0,70	56	43	21	5 21,25	5,25	6,1	6	1,01	63	56
23	2 49,25	4,5	5,3	6	0,88	51	33 $\frac{1}{2}$	July 2	5 30,8	9,55	9,13	11	0,83	72	73 $\frac{1}{2}$
30	2 54,25	5,0	4,75	7	0,68	41	26	17	5 46,7	15,9	18,5	15	1,23	67	65
1768.		0,75	1,85	3	0,616			20	5 50,8	4,1	3,33	3	1,11	68	63
Jan. 2	2 55	9,5	10,0	14	0,714	37 $\frac{1}{2}$	25	28	6 01,0	10,2	10,22	8	1,28	75 $\frac{3}{4}$	78
16	3 4,5	6,5	8,5	10	0,85	50	39 $\frac{1}{2}$	Aug. 3	6 7,55	6,55	6,65	6	1,11	67 $\frac{1}{2}$	65

N. B. The wheel escapes when the pendulum is about one degree from the lowest point. The pendulum vibrates about $1^{\circ} 25'$ on each side the perpendicular, but varies at times 3 or 4 minutes.

5. From this register it appears that the metalline rods are not precisely adjusted; the clock gaining as the weather grew warmer; though the utmost change, between winter and summer, was only from $\frac{1}{2}$ second, to $1\frac{1}{4}$ gained in a day. Probably no two rods, even of the same size and metal, expand precisely alike. The different composition of the brass, different nature of the steel, or different hardening of the wire by *drawing down*, may occasion this. Every pendulum after it is made, should be adjusted by trials. If the clock is supposed to gain half a second a day

when the thermometer is at 32, and an increase of $\frac{1}{80}$ of a second, or one *third* in a day, be allowed for every degree of the thermometer above 32, it will be found to go very exact. In the register of the clock at the observatory at Greenwich,* we find, that on September 8th, it gained 1",88 a day, the thermometer being at 60; and on February 7th, it lost 2",71, the Thermometer 44; this gives 4",59 for the variation of its rate in only seven months uninterrupted going. Again, on November 6, it gained 0",5, and on March 2d lost 2",0 a day, the thermometer each time 44. The state of the air and going of the clock was nearly the same some days before and after the times specified, and not accidental. It seems therefore, that the clock at St. John's College has been more regular than that at Greenwich.

6. Before the clock at St. John's College was placed in the observatory, it stood in a private room fixt to the wainscot only: during that time, from Jan. 8, 1765, to July 19, 1766, a register of it's going was constantly kept; from this it appears to have gone far less regularly there, than it has done since in the observatory. From December 13, 1765, to December 29, 1765, it lost half a second a day, and had gone nearly at that rate for some time before; but between December 29, and January 1st following, it suddenly altered to loosing two seconds a day: It afterward gradually abated of this, 'till on January 30, 1766, it returned to its former rate of losing half a second a day; nor were such changes uncommon. They might be owing to some motion communicated to the pendulum, by the violent shutting of the doors in the college offices under the room where it stood.

7. A register was also kept of the going of a clock with a wooden pendulum rod, but as this clock stood in the same place, fastened in the same manner as the other, it had no proper trial. Thus much may be concluded from this imperfect one, that such a pendulum rather looses in cold, and gains in warm weather, than the contrary; and the following extract from the register seems to show it.

Day

* See, *An Account of the going of Mr. Harrison's watch, at the Royal Observatory.*

In a clock that shows sidereal time, and neither gains nor loses, the same star will always pass the meridian at the same hour, minute and second: If the star *apparently* passes some seconds sooner or later at one transit, than it did at the preceeding, then the clock has *really* lost or gained so many sidereal seconds, between transit and transit, that is in a sidereal day: And at the same rate of going, the clock will lose or gain, just so many seconds of mean solar time in a mean solar day. Therefore *the variation of the clock from sidereal time per (sidereal) day*, in column 5th, page XXXI, of the above mentioned *Account*, is likewise its variation from mean time in a (*mean solar*) day.

Day of the Month.	Error by Sun too fast.	Therm.
1767.	' "	
Dec. 24	1 7	48
25	1 4½	48
27	1 0	45
28	0 59½	38
29	0 58¼	38
30	0 56¼	32
31	0 55	34
1768.		
Jan. 1	0 53¼	34
2	0 51	33
3	0 51¼	41
4	0 53	41
6	0 56	42
16	1 7½	51

The wheel has a moderate recoil; it escapes when the pendulum is $2^{\circ} 40'$ from the lowest point. The usual swing of the pendulum was $3^{\circ} 50'$ each way, which it had on Dec. 25, and Jan. 4; but between these times it fell off; and on Jan. 1, crossed only $3^{\circ} 30'$ on each side of the perpendicular.

N. B. Dec. 30, at x in the morning, thermometer 36, at 1 in the afternoon 34; and so continued all night. No fire in the room from Dec. 28 to Jan. 3.

8. As it was proper to have the observatory within the College walls for the convenience of the scholars, it became necessary to erect it on the top of a tower over one of the gate-ways, a situation otherwise by no means eligible. To give all the stability possible to the instruments, an arch was thrown cross the building from south to north, whose span within was 15 feet 6 inches, * rise 2 feet 1 inch, breadth 10 feet 9 inches and an half, thickness a brick and half: on this all the instruments are placed. To take off the lateral thrust of such an arch, which might have endangered the building, three very large beams were laid into the south and north walls; across these, just within the two walls was laid at each end a transverse piece, strongly bolted and secured by *joggles* to the three beams aforesaid; from these transverse pieces the arch springs, and thus the beams, like the string of a bow taking off all lateral thrust, the dead weight only of the arch rests upon the walls. On the crown of this arch is laid (from east to west) one large stone 2 feet 4 inches wide, 6 feet 6 inches long, and about 6 inches thick: on the ends of this stand the two shafts which support the centers of the transit telescope, each of these are 24 inches by 22, and 6 feet high, and are composed of two stones only. To the upper of these, (which is about 4 C. weight) (before it was set and while the face could be turned upwards) was leaved the apparatus for the centers of the transit. The floor of the room lies entirely on the side walls, and has no immediate connection, either with the shafts that support the transit, or the stones on which the clock and quadrant are placed; all

* The whole distance between the insides of the south and north walls, is 18 feet, 6 inches.

all which stand directly on the arch, so that the observations are no ways disturbed by the weight of persons treading on the floor of the room.

9. The transit instrument has an entire graduated circle (not a semicircle as usual) to set it to any part of the meridian. The index is a diameter, and has a *Nonius* or *Vernier* † at each end. One advantage of this is, that in turning the telescope from south to north, or downwards, (for reflections as will be explained par. 11.) the index is never off the arch, but always shows its position. Another advantage is, that the index may be set at right angles to the telescope, and in that position is much easier to get at than if parallel to it, especially if the axis is short; the index shewing zenith distances, (not altitudes) agrees better with the quadrant. The telescope has a reflecting mirror, capable of four positions, upwards either to the south or north, and side ways either east or west. The two former positions are extremely convenient for zenith stars; and indeed, necessary when the axis is so short that there is no getting to the side view for the shafts which support the centers. There is likewise a glass to look in at the end in the common manner, but is used only in adjusting the cross wires. ‡

10. The spirit level, I believe, cannot ascertain the position of the axis nearer than to a minute if so near. A plumb line might have been easily applied to the telescope, and is certainly more exact.* Mr. M—— proposed taking transits by reflection from the surface of a fluid, to find whether the axis was level: for if the axis is truly level, transits by such reflection will be seen at the same instant, as when viewed directly; but if the axis is not level, these transits will appear earlier or later, as the western or eastern end of the axis is the lowest. Let therefore the passage of some star near the zenith, over the three wires, be taken directly, and often enough to ascertain the intervals of time between them; then let the passage over the extreme wires be taken directly, but the middle by reflection; in this case one interval will be increased and the other diminished by all the time that the middle transit so observed, appears earlier or later, than if it had been taken directly. In like manner, this error may be discovered by observing

† This method of subdividing degrees into minutes now generally in use, has been commonly attributed to *Petrus Nonius* a Spaniard, in 1541, and it has accordingly borne his name; but it was in reality the invention of *Peter Vernier*, a Frenchman, in 1631; and of late both French and English writers have called it *Vernier*. See De la Lande's Astr. Art. 1857. and Philos. Transf.— See an excellent account of this and other inventions for the same purpose in Robins's tracts. Vol. 2. page 265.

‡ The drawing and dimensions of this telescope are given in paragraph 67.

* See De la Lande's Astronomy. Art. 2083.

serving the transit of three stars over the middle wire only, first of all directly, to learn the true intervals of their passage, and then the two extremes directly, and the middle by reflection. In transits of the sun, the passage of both limbs over one wire may be taken directly, to ascertain the true *mora*, and the passage over the other wires alternately direct and by reflection: the inequality of the *mora* so taken, will discover the error in the level of the axis.

11. Three methods of reflection were made use of. A round glass, whose surfaces were truly parallel, floating on quicksilver, 2d, quicksilver only, 3d, water. In the first of these, the reflection was very bright, and the surface not easily disturbed; but the level of the reflecting surface much to be suspected: the least bubble of air between the glass and quicksilver, would manifestly raise one side of it, and it was difficult to get quit of all these bubbles. If the glass floated to the side of the vessel or near it, the depression of the quicksilver there, plainly affected its level, nor could one be sure that the glass itself was of the same density and weight in every part, though there was evidence enough to prove the parallelism of the sides to be very exact. 2d, The reflection from quicksilver itself is very bright, but the fluid is so susceptible of motion, that the wind by shaking the whole building, or the shutting of a door in a very distant part of it, would disturb the quicksilver very much, and it took so long to settle, that this method could seldom be practised. 3d, Water is less liable to be disturbed, and settles sooner, but the reflection is very faint. † The light from the ceiling of the room, reflected from the water into the telescope, effaced the image of all stars, but those of the first magnitude: nor was it so free from tremors as to be much depended on. On the ground, a water-reflection may be very useful; for the image of the sun and of other objects, seen very obliquely, is distinct enough in a telescope that magnifies forty times, when the water is still, and the surface so large that the telescope may be kept clear of irregular light reflected from parts near the sides of the vessel.

12. The

† I found oyl nearly as susceptible of tremors as water. Treacle, recommended by some, is apt to have air-bladders on the surface, nor can we be sure that the surface of so imperfect a fluid will be level.

In all these cases, the fluid must be sheltered from the action of the wind on its surface by a cover made with two glass planes, which can be set to any angle, so that the incident and reflected rays may pass perpendicularly through them. The vessel that contains the fluid should stand on the ground, and have no communication with this cover; for the wind will shake the cover, and that will give a tremor to the fluid, if they are connected.

A glass mirror (whose surfaces are parallel) set true with a spirit level, makes a good reflecting horizon, in cases where a fluid cannot be used.

12. The foregoing methods by reflection failing, and the spirit level seeming insufficient to ascertain the position of the axis, I endeavoured to determine the position of the instrument with respect, both to the meridian, and the horizon, by astronomical observations only, viz. by the upper and under transits of the circumpolar stars, * compared with corresponding altitudes of the sun and stars. If the line of collimation of the transit telescope be continued, it will describe a great circle in the heavens; the perpendicular distance of this circle from the pole may be inferred from transits of the circumpolar stars; this determined, the points in which that circle intersects the meridian and horizon, and its inclination to each of them, may be found by corresponding altitudes. Before we put down those observations it must be premised, that from the settling of the arch the telescope manifestly changed its position; this was first discovered by the transits of Capella above and below the pole, in the end of August; but in December the wire plainly cut a part of the tracery in the stone battlements of King's Chapel, west of that to which it was at first set. After the beginning of December no change of the position was observed, and it still keeps the same, as may be collected from the observations on Capella, July 2, 1768. The later ones of July 20, and 27th, seem indeed to indicate some change. †

13. In

* In transits of the circumpolar stars, the same wire which the star passes first in the upper transit, is the third or last in the under transit, and contrariwise. As the intervals between the wires are not precisely equal, it is necessary to attend to this circumstance.

The pole star in October appeared larger than the wire, and ill defined; its motion was so slow, that for ten seconds together, the star appeared to be exactly bisected, the light on each side the wire seeming equal all that time. In January, as it came into day-light, it began to appear smaller and better defined, and in the later transits was intirely covered by the wire for a time. On these accounts, the pole star does not seem the fittest for this purpose of ascertaining the position of the telescope. Astronomers differ much on this point, some preferring those stars which are most remote from the pole, and have the quickest motion; others those nearest it, which describe the smallest circle. The quicker the motion of the star, the more accurately may the instant of its transit be ascertained; but as the clock distinguishes no portion of time less than a second, a velocity that could mark out parts of a second is useless. On the other hand, the less the circle described, the greater will be the difference (in time) between the intervals of the two transits, when that circle is not bisected by the telescope: But the motion of the star may be so slow as to make the instant which terminates these intervals, and consequently their duration uncertain to many seconds. Therefore those stars seem the fittest for this purpose, whose motion, *when magnified by the telescope*, is just quick enough to make them pass the wire, with certainty to a second; consistently with this, the nearer to the pole, the better.

† The difference between the intervals of the transits (in column 4 of the following table) which in February 1768, was 9"; on July 27, following, was only 6". If the motion

13. In comparing the transits of circumpolar stars, the interval of time between the under and upper transits, while the star described the eastern part of its parallel, was always less than the other interval wherein it described the western part. In the first column of the following table is the day of the month, in the second the star observed, in the third the part of the parallel described between the observed transits, which is distinguished by E for the eastern, or W for the western part. When the interval of both parts was observed (by taking three successive transits) it is marked by E and W. In the fourth column is the difference between the intervals of the transits, that is, the difference between the observed time wherein the eastern part, and that wherein the western part was described; when only one interval was observed, the other is inferred on a supposition that both intervals together, or the time of an entire revolution of the stars as shown by the clock was $XXIII^h 56' 5''$, the clock gaining one second a day on mean time.* In the fifth column is the perpendicular distance of the great circle described by the transit telescope from the pole, or the arch P V in figure 5, plate VII, and is derived from the numbers in the fourth column by the rule in par. 143.

Days

tion of the earth round its axis is not equable, and this arises from any cause depending on the position of the moon with respect to the parts of the earth, it may account for this change of $3''$. Constant observations of the double transits of the circumpolar stars, are most likely to discover whether there really is any such inequality in the diurnal rotation, as some Astronomers have suspected, See *Hooke's* posthumous works, page 545.

* Hence one second of time by the clock answers to 15,0409 seconds of a degree in the revolution of the stars, and $\frac{1}{4}$ of the number of seconds in the fourth column multiplied by 15,0409 gives the angle R P S, par. 139. in seconds of a degree.

In these computations when arches less than a single minute occur, instead of the ratio of the sines or tangents of such arches taken to entire seconds only, it will be more accurate to use that of the arches themselves expressed in seconds and decimal parts of a second. Thus the rule in par. 143, for finding the arch P V, will become radius, to the tangent of P R, as R P S expressed in seconds and decimal parts of a second, is to P V expressed in like manner. Neglecting the minute difference between such arches and their sines or tangents, will occasion far less error, than neglecting parts of a second in taking their sines or tangents out of the tables.

Days of the Month.	Stars observed.	Obf. part of the parallel.	Seconds of time.	Seconds of a degree.	Days of the Month.	Stars observed.	Obf. part of the parallel.	Seconds of time.	Seconds of a degree.
1767.			"	"	1768.			"	"
July 11, 12		E W	3	11	Jan. 22		W	10	
23, 24		W	3		Feb. 3, 4	α Persei	W	7	
26		E	3		4, 5		E W	9	29
Aug. 1, 2	Capella	E W	2		Jan. 22		E	37	} 33
2, 3		E W	$3\frac{1}{2}$	} $16\frac{1}{2}$	Feb. 3, 4	β Ursa minoris	E	31	
27, 28		E W	$4\frac{1}{4}$		4, 5		W E	31	
28, 29		E W	$4\frac{3}{4}$						
Nov. 13, 14		E W	10	} 24	Jan. 22		E	31	} 34
Dec. 1, 2	α Ursa majoris	E	15		Feb. 3, 4	γ Ursa minoris	E	31	
10, 11		E W	$12\frac{1}{2}$		4, 5		W E	$29\frac{1}{2}$	
Dec. 1, 2		E	13	} 29	Feb. 5		W	9	} 33
10, 11	β Ursa majoris	E W	11		12, 13	Capella	W E	9	
Dec. 10, 11					April 1, 2		W E	$8\frac{1}{2}$	
Dec. 10, 11		W	221	} 28	March 18		E	10	} 33
11, 13	Polaris	E	221		23		E	8	
23		W	221		April 1, 2	α Cygni	E W	$7\frac{1}{2}$	
					2, 3		E W	9	

14. If we take the arch $PV = 33''$, and the error in the transit of Aldebaran, found by corresponding altitudes, on Nov. 27,* $= 3\frac{1}{4}$ seconds of time; then the distance of the intersection of the aforesaid great circle and meridian from the pole, or arch PZ , (plate VII, fig. 5.) is $29^\circ 29' 10''$.† From the error in the transit of the sun found in like manner March 3, 1768, $= 4\frac{3}{8}$ seconds of time, we have $PZ = 25^\circ 26' 20''$. From the error in the transit of γ Leonis, March 5, $= 3\frac{7}{8}$ seconds of time, $PZ = 24^\circ 56' 30''$. From the error in the suns transit, April 22, $= 3,275$ seconds of time, $PZ = 30^\circ 19' 20''$. The mean of all these gives $PZ = 27^\circ 32' 50''$, or $27^\circ 33'$ nearly, and the point Z is $10^\circ 14'$ north of the zenith. By the errors in the transits of δ and ϵ Cassiopeæ, found as before on Nov. 28, this point lies between those stars, and therefore nearer to the zenith; but at that time the arch PV did not seem to be more than $24''$.

Supposing the arch $PV = 33''$, $PZ = 27^\circ 33'$, ZX , or the distance of the point of intersection from the zenith $= 10^\circ 14'$, the error of the telescope in the level is $12'',89$, and the error in azimuth $1' 10'',21$ to the west. Had the axis been perfectly level, and the arch $PV = 33''$ as before, then the error in azimuth would have been $54''$.

15. Hence the passage of the sun, observed by the transit telescope, will be later than his passage over the true meridian, more or less according to his declination, as in the following table.‡

© Declinat.

* See pages 31. 32.

† See paragraphs 146. 150, 151.

‡ See par. 140.

☉ Declinat. North.			Error in Transit		☉ Declinat. South.			Error in Transit	
°	'	"	"	'''	°	'	"	"	'''
23	28	10	3	16	0			4	13
20			3	25	5			4	24
15			3	38	10			4	36
10			3	50	15			4	48
5			4	01	20			5	1
0			4	13	23	28	10	5	10

16. It remains to set up a mark on the parapet of King's College Chapel in the true meridian. The distance of the point of the parapet now cut by the wire, from the telescope may be easily found trigonometrically, the parapet wall of the chapel affording a long and level base. This obtained it will be easy to find the distance of the mark to be set up, from the place at present cut by the wire so as to make with it, at the telescope, an angle of $1' 10'', 21$. A mark being thus set up, the truth of its position may be examined by astronomical observations as before.

17. The quadrant is 18 inches radius, and is mounted on a vertical axis, by which it can be turned to any azimuth: It can likewise be moved by rack-work into any plane, but having no perpendicular bars* is much too weak to be trusted in any but a vertical position, and the design of the rack-work is such, as makes it necessary to have a long and tender neck to the vertical axis, which weakens it in every position. Dr. Bliss, to whom this quadrant formerly belonged, prevailed on Mr. Bird (much against his inclination and judgment) to rivet a new limb upon the old one (which had diagonal divisions,) to divide it afresh in his own method, to make two new telescopes to it, and to mount the whole on a pedestal. The division into 96 parts is in every quadrant preferable to that into 90, and is very evidently so in this; wherefore all the calculations here given are made from the measures taken on that scale, and the scale of degrees is considered only as a check upon any error in reading off the parts. There is likewise a micrometer-screw with an index, to subdivide minutes into every four seconds, but it seems not so certain, (in this quadrant at least) as estimating the fractional parts of a minute by the eye.

18. The quadrant is set upright by a plumb line seen against two very fine points, in the manner of that at Greenwich. This method seems more exact than the very best spirit levels, even those that are *ground*.† For when

* Perpendicular bars, are those whose plane is perpendicular to the plane of the quadrant, and are fastened on the backside of it; their use is to strengthen the plane of the quadrant.

† See *De la Lande's Astronomy*, Art. 1911.

when the radius of curvature of the upper side of the tube is very great, the force with which the bubble rises to the highest point is so very small, that the least adhesion of the liquor to the glass will stop it, and its place of rest will be uncertain.‡ A plumb line of fine wire is liable to no uncertainty as to its perpendicular situation, is extremely sensible, and if the points are fine, and the wire so small as not to cover them, it will be easy to see by a magnifying glass when they are bisected, and thus the quadrant may be set to a few seconds.—In some circumstances indeed a plumb line cannot be used; and in all a spirit level gives by far the least trouble.

19. The line of collimation was rectified on the 7th of March, 1767, by taking off the telescope and reversing it in Mr. Bird's method,† and was again examined Aug. 22, in the same way and found to be true: nevertheless, as the divisions on the limb are carried beyond the point of *o* on what is called the *arch of excess*, the line of collimation was also examined by comparing the zenith distances of several stars taken on the arch of excess, with the same taken on the quadrantal arch.

20. There is some nicety in taking the distance of stars from the zenith, when they are very near it, especially by a *pillar quadrant*, or one that turns round on a vertical axis. In all quadrants, a line drawn from the center of the object glass, to the intersection of the wires, ought to be parallel to the plane of the arch,§ and then all distances should be taken as near that intersection as possible. When this is not the case, (and it seldom is) then the distances should be taken, not on the intersection, but on another point of the horizontal wire, || to which if a line be drawn from the center of the object glass, it will be parallel to the plane of the arch.* In a pillar quadrant you may bring this point of the wire to the object,

‡ For this reason it is best to have the bubble large, that its force may be the greater.

† See the method of dividing astronomical instruments by Mr. Bird, page 9.

§ The notch from which the plumb line hangs, ought to be very exactly in the plane of the arch, otherwise it will be impossible to set that plane upright; if this is not the case, or if all parts of the arch are not in one plane; then a plane passing through the plumb line, and a given point in the arch, is to be taken for the plane of the arch in that point or part of it.

|| The horizontal wire is always parallel to the horizon the vertical wire is in the plane of a vertical circle; the former is perpendicular, the latter parallel to the plane of the arch: zenith distances are taken on the former, transits on the latter.

If the telescope is furnished with a side-glass to look into it in a direction perpendicular to the plane of the quadrant, the wires will appear in this side view, to lie in a plane parallel to that of the quadrant, the horizontal wires always seeming parallel, and the vertical wires perpendicular to the axis of the telescope.

* A line so drawn is properly the line of collimation.

object by turning the whole instrument round on its vertical axis, and then the plane of the arch will be in the same azimuth with the object, and the zenith distance truly shown upon it. Now this method fails, in taking on the meridian, the distance of stars from the zenith which are very near it; for then turning the quadrant on this axis will hardly change the place of the star on the wire. In this case therefore the quadrant should be first set very nearly in the meridian, by bringing the intersection of the wires on some low star, at the time of its transit. The quadrant thus set, and the vertical axis fixt, the distance of the zenith star must be taken at the time it passes the meridian (shown by the transit telescope) on whatever part of the horizontal wire it happens then to be. This point of the wire is that on which the distances of all other stars ought to be taken. In setting the quadrant a second time, this point, not the intersection of the wires, is to be brought on the low meridian star, and repeating the rest of the work, a more correct place of this point will be found.

21. Another method of finding this point on the horizontal wire is as follows. Set the telescope parallel to the plumb line or nearly so; the telescope continuing in this position, adjust the quadrant so that the plumb line hanging close to the arch (but not touching it) may constantly bisect both the points, while the quadrant turns quite round on the vertical axis. This axis will then be parallel both to the plane of the quadrant, and to the plumb line. When some star within a degree of the zenith crosses the meridian, move the telescope until the horizontal wire is upon, or rather short of the star; then turning the quadrant round upon the axis, the star will seem to describe a circular arch, either touching that wire or intersecting it in two points, according as the telescope is set to the exact zenith distance of the star or is short of it. The point of contact in one case or the middle between the points of intersection in the other is that required.

22. In this method there is no necessity of observing either a zenith star or one in the meridian. The quadrant once adjusted as before, its axis may be inclined so as to point to any other star: the pole star is the best for this purpose, its motion being so slow that it may be considered as stationary. If the axis of the quadrant and the telescope are both directed towards it, by changing gradually the position of each, you may at last bring it to pass, that the star shall keep its place on the wire while the quadrant is turned quite round on the axis, and then they are both directed accurately to that star. The point of the wire on which the star is thus stationary, is that sought, and the index then shows on the limb the error of the line of collimation. If indeed the quadrant is heavy or its construction weak, this

this method must fail, because both the axis and plane of the quadrant would bend, and the line of collimation not keep its parallelism, while the quadrant is turned round.

23. Another method for examining the parallelism of the axis of the telescope* to the plane of the quadrant, is described in *De la Lande's Astronomy*, art. 2050, and 2073. In article 2052, is a method of computing the errors in taking zenith distances that arise from the want of this parallelism, but it is better to take the distances on the proper part of the wire than allow for the errors in taking them on any other.

24. Zenith distances of stars taken both on the arch of excess, and the quadrantal arch, for finding the error of the line of collimation.†

Stars observed.	Days of observation.	Mean of the several obs. zenith distances.		Semi sum, or true zen. dist.	Semi differ. or Er. line collimation.
		Parts of 96	Deg. M. S.		
β Draconis	June 21, 24, July 3, 13, 17, 27. <i>arch of ex.</i>	0 2 6 $\frac{13}{30}$	0 16 51,47	0 16 33,1	18,38
	June 22, 25, July 2, 20, 28. <i>quad. arch</i>	0 2 4 $\frac{29}{30}$	0 16 14,71		
γ Draconis	June 22, 25, 26, July 2, 10, 20. <i>arch of ex.</i>	0 5 13 $\frac{31}{30}$	0 41 14,84	0 40 52,8	21,95
	June 21, 24, July 3, 13, 17, 18. <i>quad. arch</i>	0 5 12 $\frac{7}{30}$	0 40 30,90		
Lyra	June 25, 26, July 2, 17. <i>arch of excess</i>	14 4 4 $\frac{7}{8}$	13 37 46,04	13 37 25,8	20,17
	June 21, 24, 30, July 3, 13, 20, 28. <i>quad. ar.</i>	14 4 3 $\frac{29}{30}$	13 37 05,70		

Hence the error of the line of collimation may be estimated at 20". If it be computed from the observations in December, it will be found near double of this, but most of the distances on the arch of excess were then taken once only, viz. December 13, and the quadrant was (of necessity) set, not by the usual plumb line, but by another adjusted by the common one. In doing this there is great danger of error in a weak quadrant loaded with the vessels of water in which the plummets hang. In observations made at one such setting of the quadrant, whatever error there is, it must enter into all of them.

25. Some

* By the *axis of the telescope*, is here meant a line drawn from the center of the object glass to the intersection of the wires, fall where it will; when this line is parallel to the plane of the quadrant, it is then the *line of collimation*.

† In the following computations, $\frac{1}{6}$ of a division of the Vernier is allowed for + or - in the observed zenith distances.

25. Some of the observations (in December and January,) were made on the arch of excess, by first setting the quadrant true, and then pushing the plumb line aside to make room for the telescope; but in this case the position of the quadrant may alter without any possibility of discovering it.

26. The two stars β and γ Draconis are so near the zenith, that their distances can be taken on the arch of excess without removing the plumb line at all; and the distance of Lyra is so great as to carry the telescope clear beyond the place of the plumb line, so that the observations on these stars are not only more in number, but more accurate than those in December, and their consistency shows it.

The two stars ι , κ , Ursæ majoris, March 11th and 18th, likewise give 20" for the error of the line of colimation, whence we may conclude it not subject to variation.

27. The quadrant was likewise examined by inverting it in the following manner. A board was set upright at the distance of 400 yards, having two holes in it, through which the sky appeared, these holes were each 1,69 inches diameter, and 18,7 inches distant from one another, (the telescope becoming so much lower by inverting the quadrant.) The centers of the holes were placed in a line perpendicular to the horizon, and their diameters were such, that the wire of the quadrant just covered them at that distance.*

The following distances† were taken August 6, 1768, at XI in the forenoon.

	Parts of 96.			
Quadrant as usual, zenith distance of the upper hole, --	93	6	10	c
Repeated —————	93	6	10	c
Again, by another person, the quadrant re-adjusted, —	93	6	10	
Again, by the same, —————	93	6	10	—
Again, by the former person, —————	93	6	10	—
Quadrant inverted, distance of the lower hole from the nadir	98	1	6 $\frac{1}{2}$	
Repeated — — — — —	98	1	6 $\frac{1}{2}$	
By another person, quadrant re-adjusted, — — — — —	98	1	6 $\frac{2}{3}$	
Again, by the former person, quadrant re-adjusted, —	98	1	6 $\frac{3}{4}$	
Again, by the same, —————	98	1	7	—
Again, by the former, — — — — —	98	1	6 $\frac{3}{4}$	

Qua-

* Larger holes, about 4 inches diameter, are rather preferable for this purpose: their bisection by the wire may be exactly distinguished.

† When the quadrant is in its usual position, the distances shown on the limb are reckoned from the zenith; when the quadrant is inverted, those distances are reckoned from the nadir.

		Parts of 96.
Quadrant restored to its usual position, upper hole, —	93 6 10 —	
Again, by another person, — — —	93 6 10 +	
Again, by the former person, — — —	93 6 10 —	

At IV in the afternoon of the same day.

	Upper hole. Parts of 96.	Lower hole. Parts of 96.
Quadrant inverted — — —	98 2 $0\frac{1}{2}$	98 1 7 c
Again — — —	98 2 $0\frac{2}{3}$	98 1 7 c
Again — — —	98 2 $0\frac{1}{2}$	98 1 $6\frac{2}{3}$
Again — — —	98 2 $0\frac{1}{2}$	98 1 7 +
Quadrant restored to its usual position	93 6 10 c	93 7 4 c
Again — — —	93 6 10 +	93 7 4 +
Again — — —	93 6 10 +	93 7 4 +

Mean of the 8 morning observations.

	Parts of 96.	Deg. M. S.
Quadrant as usual, upper hole, —	93 6 $9\frac{1}{16}$	87 57 48,17

Mean of the 6 morning observations.

	Parts of 96.	Deg. M. S.
Quadrant inverted, lower hole, —	98 1 $6\frac{2}{3}$	92 2 27,65
Semi sum		90 0 07,91

Hence, if the quadrantal arch is exactly 90 degrees, the error of the line of collimation is 7",9 to be subtracted: but if the error of the line of collimation be 20" to be added, (as is inferred from the foregoing observations,) then the quadrantal arch falls short of 90 degrees by 27",9.

Computation

28. Computations of the latitude from the zenith distances of the sun's lower and upper limb, taken when he was near the solstices.

1767.	Partsof96	Degrees.	1768.	Partsof96	Degrees.
		° ' "			° ' "
Dec. 18. lower limb	80 7 3½	75 50 45,4	June 17. lower limb	30 7 13½	29 2 34,7
upper limb	80 2 8½	75 17 47,9	upper limb	30 3 5	28 30 47,4
* semi-difference		16 28,7	femi-difference		15 53,6
† refr. 3' 41", paral. 9"		3 32	refr. 30", 4, paral. 4"		26,4
error of line of collimat.		20	error of line of collimat.		20
zenith dist. ☉'s center		75 38 8,6	zenith dist. ☉'s center		28 47 27,4
declination, subtract		23 25 22,	declination, add		23 25 41
Latitude		52 12 46,6	Latitude		52 13 8,4
Dec. 20. lower limb	80 7 9½	75 53 23,6	June 21. lower limb	30 7 7½	28 59 52
upper limb	80 2 13½	75 20 4,1	upper limb	30 2 14½	28 27 47,2
femi-difference		16 39,7	femi-difference		16 2,4
refr. 3' 41", 4, paral. 9"		3 32,4	refr. 30", 9, paral. 4"		26,9
error of line of collimat.		20	error of line of collimat.		20
zenith dist. ☉'s center		75 40 36,2	zenith dist. ☉'s center		28 44 36,5
declination, subtract		23 27 43	declination, add		23 28 10
Latitude		52 12 53,2	Latitude		52 12 46,5
Dec. 22. lower limb	80 7 10½	75 53 41,1	June 29. lower limb	31 1 8½	29 14 31
upper limb	80 2 15½	75 20 48,3	upper limb	30 5 0	28 42 39,4
femi-difference		16 26,4	femi-difference		15 55,8
refr. 3' 48", 6 paral. 9"		3 37,6	refr. 31", paral. 4"		27
error of line of collimat.		20	error of line of collimat.		20
zenith dist. ☉'s center		75 41 12,3	zenith dist. ☉'s center		28 59 22,2
declination, subtract		23 28 12	declination, add		23 13 21
Latitude		52 13 0,3	Latitude		52 12 43,2
Dec. 30. lower limb	80 5 3½	75 36 41,6	July 1. lower limb	31 2 10½	29 22 16,8
upper limb	80 0 8	75 3 30,9	upper limb	30 6 2½	28 50 38,4
femi-difference		16 35,3	femi-difference		15 49,2
refr. 3' 50", paral. 9"		3 41	refr. 30", 3, paral. 4"		26,3
error of line of collimat.		20	error of line of collimat.		20
zenith dist. ☉'s center		75 24 7,2	zenith dist. ☉'s center		29 7 13,9
declination, subtract		23 11 12	declination, add		23 5 32
Latitude		52 12 55,2	Latitude		52 12 45,9
Jan. 2, 1768. lower limb	80 3 3½	75 22 37,9	July 2. lower limb	31 3 5	29 27 2,4
upper limb	79 6 8½	74 49 33,8	upper limb	30 6 12	28 54 57,6
femi-difference		16 32	femi-difference		16 2,4
refr. 3' 45", paral. 9"		3 36	refr. 30", 2, paral. 4"		26,2
error of line of collimat.		20	error of line of collimat.		20
zenith dist. ☉'s center		75 10 1,8	zenith dist. ☉'s center		29 11 46,2
declination, subtract		22 57 5	declination, add		23 1 1
Latitude		52 12 56,8	Latitude		52 12 47,2
June 16. lower limb	31 0 1	29 4 11,3	Mean of 5 latitudes from obser-		
upper limb	30 3 8	28 32 6,5	vations near the winter solstice }		52 12 54,4
femi-difference		16 2,4	Mean of 6 latitudes from obser-		
refr. 31", 4, paral. 4"		27,4	vations near the summer solstice }		52 12 51,4
error of line of collimat.		20	Mean of both		52 12 52,8
zenith dist. ☉'s center		28 48 56,3			
declination, add		23 24 1			
Latitude		52 12 57,3			

* The wire in the telescope subtends an angle of 14 or 15 seconds, therefore the sun's semidiameter inferred from the zenith distance of the upper and lower limb cannot be accurate.

† The proper allowance is made for variation of refraction, depending on the state of the barometer and thermometer on each day respectively. See tables belonging to the Nautical Ephemeris, p. 130.

54 REMARKS ON THE OBSERVATIONS.

29. Whatever be the obliquity of the ecliptic, the difference of a few minutes will not sensibly affect the sun's distance from the Tropic on any given day near the solstices. This distance (or difference whereby the sun falls short of the tropic) may be found from any ephemeris, by subtracting the declination for the given day, from the assumed obliquity of the ecliptic, by which that declination was computed. If to the zenith distances of the sun's center (set down in the course of the foregoing computations) we add or subtract the sun's distance from the tropic for the given day, found as before, we shall get the zenith distances of both tropics by a method which supposes nothing previously known but parallax and refraction. The semi-sum of these two distances is the latitude of the place, and their semi-difference the obliquity of the ecliptic.

Day of the Month. 1767.	Zenith Dist. Sun's Center by the Observations.	Sun's Dist. from Tropic by Naut. Eph.	Zenith Dist. of the Tropic of φ	Day of the Month. 1768.	Zenith Dist. Sun's Center by the Observations.	Sun's Dist. from Tropic by Naut. Eph.	Zenith Dist. of the Tropic of $\odot$
	$^{\circ}$ $'$ $''$	$'$ $''$	$^{\circ}$ $'$ $''$		$^{\circ}$ $'$ $''$	$'$ $''$	$^{\circ}$ $'$ $''$
Dec. 18	75 38 8,6	2 52,4	75 41 1	June 16	28 48 56,3	4 11,3	28 44 45
20	75 40 36,2	31,4	75 41 7,6	17	28 47 27,4	2 31,3	28 44 56,1
22	75 41 12,3	2,4	75 41 14,3	21	28 44 36,5	2,3	28 44 34,2
30	75 24 7,2	17 2,4	75 41 9,6	29	28 59 22,2	14 51,3	28 44 30,9
Jan. 2	75 10 1,8	31 9,4	75 41 11,2	July 1	29 7 13,9	22 40,3	28 44 33,6
				2	29 11 46,3	27 11,3	28 44 35
	Mean		75 41 8,7		Mean		28 44 39,1
Their semi-sum, or Latitude of the place							52 12 53,9
Semi-difference, or obliquity of the ecliptic							23 28 14,8

30. Computations of the Latitude from the zenith distances of circumpolar stars, taken below and above the pole.

		Parts of 96	Degrees.
			$^{\circ}$ $'$ $''$
POLARIS. } Mean of the several zenith distances taken on December 3, 10, 23, 30.	Below the pole	42 2 12 $\frac{17}{48}$	39 41 59,5
	Refraction		47
Dec. 9, 11, 18, 23, 28, 30. Jan. 2, 16,	Corrected zenith distance		39 42 46,5
	Above the pole	38 1 13 $\frac{77}{96}$	35 50 35,8
	Refraction		41
	Corrected zenith distance		35 51 16,8
	Semi-sum or zenith dist. pole		37 47 1,6
	Complement		52 12 58,4
Compl't. of semi-dif. } or apparent declinat. }	Error of line of collimat. subt,		20
	Latitude		52 12 38,4

β Ursæ

REMARKS ON THE OBSERVATIONS. 55

		Parts of 96	Degrees.
			° ' "
β <i>Ursæ Minoris</i> , } Mean of the several zenith distances taken on Jan. 16, 19, 22, 26, Feb. 3, 5, Barom. 30, Thermom. 36,	Below the pole	56 1 7 $\frac{1}{2}$	52 40 18,9
	Refraction		1 18,7
	Corrected zenith distance		52 41 37,6
	Jan. 22, Feb. 4, 5, Above the pole	24 3 3	22 52 24,7
	Refraction		24,2
	Corrected zenith distance		22 52 48,9
	Semi-sum or zenith dist. pole		37 47 13,2
	Complement		52 12 46,8
	Error of line of collimat. subt.		20
	Latitude		52 12 26,8
Compl ^t . of semi-dif. } 75° 5' 35", 1 or apparent declinat. }			
γ <i>Ursæ Minoris</i> , } Mean of the several zenith distances taken on Jan. 16, 19, 22, 26, Feb. 3, 5, Barom. 30, Thermom. 36,	Below the pole	58 6 5 $\frac{1}{2}$	55 6 57,5
	Refraction		1 25
	Corrected zenith distance		55 8 22,5
	Jan. 22, Feb. 5, Above the pole	21 6 5 $\frac{1}{2}$	20 25 51,2
	Refraction		22
	Corrected zenith distance		20 26 13,2
	Semi-sum or zenith dist. pole		37 47 17,8
	Complement		52 12 42,2
	Error of line of collimat. subt.		20
	Latitude		52 12 22,2
Compl ^t . of semi-dif. } 72° 38' 55", 4 or apparent declinat. }			
α <i>Ursæ Majoris</i> , } Mean of the several zenith distances taken on Nov. 14, 18, 21, Dec. 11, 12, Barom. 29,975, Thermom. 42,	Below the pole	69 0 10 $\frac{7}{8}$	64 45 44,8
	Refraction		2 4
	Corrected zenith distance		64 47 48,8
	Dec. 3, 10, Above the pole	11 3 15	10 46 26,1
	Refraction		10,7
	Corrected zenith distance		10 46 36,8
	Semi-sum or zenith dist. pole		37 47 12,8
	Complement		52 12 47,2
	Error of line of collimat. subt.		20
	Latitude		52 12 27,2
Compl ^t . of semi-dif. } 62° 59' 24" or apparent declinat. }			
Mean from these three last stars			52 12 25,4

31. Computations of the latitude from the stars whose zenith distances were taken both on the quadrantal arch and arch of excess. See p. 50.

July 1, 1768.					° ' "
β <i>Draconis</i>	Declination in 1750, by <i>Connoissance des Mouvements Célestes</i> 1762	—	—	—	52 29 49,8
	Decrease in 18 $\frac{1}{2}$ years	—	—	—	— 56,6
	Aberration, <i>Sun's Longitude</i> 3° 10'	—	—	—	+ 5,8
	Nutation, <i>Moon's Node</i> 9 12	—	—	—	— 2,4
	Apparent declination	—	—	—	52 28 56,6
	True zenith distance (See page 50)	—	—	—	16 33,1
	Latitude	—	—	—	52 12 23,5
	Declination in 1750, by <i>Connoissance, &c.</i> 1762,	—	—	—	51 31 30,6
	Decrease in 18 $\frac{1}{2}$ years	—	—	—	— 14,8
	Aberration, <i>Sun's Longitude</i> 3° 10'	—	—	—	+ 4,2
γ <i>Draconis</i>	Nutation, <i>Moon's Node</i> 9 12	—	—	—	— 1,6
	Apparent declination	—	—	—	51 31 30,6
	True zenith distance	—	—	—	40 52,8
	Latitude	—	—	—	52 12 23,4

July 1, 1768.

Lyra

Declination in 1750, by *Connoissance*, &c. 1763,Increase in $18\frac{1}{2}$ yearsAberration, *Sun's Longitude* $3^s 10^o$ Nutation *Moon's Node* $9 12$

Apparent declination

True zenith distance

Refraction

Latitude

Mean from these three stars

°	'	"
38	34	1,4
		+45,8
		+ 1,4
		— 1,2
38	34	47,4
13	37	25,8
		13,5
52	12	26,7
52	12	24,5

32. Computations of the latitude from the observed zenith distances of several stars, whose declinations are given in page 15 of the tables belonging to the Nautical Ephemeris.

	Parts of 96	Degrees.																					
<i>α Arietis</i> , } Mean of the several zenith distances taken on Dec. 23, 29, 30, Jan. 2, 15, 16, 19, 26. Refraction for altitude $60^o 10'$ Barom. 29,74, Thermom. 32,4 Error of line of collimation True zenith distance Declination 1767 Increase in 1,03 years Aberration, <i>Sun's Longitude</i> $9^s 20^o$ Nutation, <i>Moon's Node</i> $9 20$	31 6 $8\frac{7}{8}$	<table> <tr><th>°</th><th>'</th><th>"</th></tr> <tr><td>29</td><td>49</td><td>50,2</td></tr> <tr><td></td><td></td><td>34,7</td></tr> <tr><td></td><td></td><td>20</td></tr> <tr><td>29</td><td>50</td><td>44,9</td></tr> <tr><td>22</td><td>21</td><td>32,4</td></tr> <tr><td>52</td><td>12</td><td>17,3</td></tr> </table>	°	'	"	29	49	50,2			34,7			20	29	50	44,9	22	21	32,4	52	12	17,3
°	'	"																					
29	49	50,2																					
		34,7																					
		20																					
29	50	44,9																					
22	21	32,4																					
52	12	17,3																					
Latitude		52 12 17,3																					
<i>Aldebaran</i> , Mean of the zenith distance taken on Jan. 16, 19, 26, Feb. 4, 5, Refraction for altitude $53^o 50'$ Barom. 29,9, Thermom. 38,4 Error of line of collimation True zenith distance Declination 1767 Increase in 1,07 years Aberration, <i>Sun's Longitude</i> $10^s 5^o$ Nutation, <i>Moon's Node</i> $9 20$	38 4 $9\frac{8}{15}$	<table> <tr><th>°</th><th>'</th><th>"</th></tr> <tr><td>36</td><td>9</td><td>48,8</td></tr> <tr><td></td><td></td><td>42,6</td></tr> <tr><td></td><td></td><td>20</td></tr> <tr><td>36</td><td>10</td><td>51,4</td></tr> <tr><td>16</td><td>1</td><td>31,7</td></tr> <tr><td>52</td><td>12</td><td>23,1</td></tr> </table>	°	'	"	36	9	48,8			42,6			20	36	10	51,4	16	1	31,7	52	12	23,1
°	'	"																					
36	9	48,8																					
		42,6																					
		20																					
36	10	51,4																					
16	1	31,7																					
52	12	23,1																					
Latitude		52 12 23,1																					
<i>Rigel</i> , Mean of the zenith distance taken on Jan. 16, 19, 26, Feb. 4, 5, Refraction for altitude $29^o 20'$ Barom. 29,903, Thermom. 38,4 Error of line of collimation True zenith distance Declination 1767 Decrease in 1,07 years Aberration, <i>Sun's Longitude</i> $10^s 5^o$ Nutation, <i>Moon's Node</i> $9 20$	64 5 $10\frac{5}{6}$	<table> <tr><th>°</th><th>'</th><th>"</th></tr> <tr><td>60</td><td>39</td><td>55</td></tr> <tr><td></td><td></td><td>1 44,7</td></tr> <tr><td></td><td></td><td>20</td></tr> <tr><td>60</td><td>41</td><td>59,7</td></tr> <tr><td>8</td><td>29</td><td>12,7</td></tr> <tr><td>52</td><td>12</td><td>47</td></tr> </table>	°	'	"	60	39	55			1 44,7			20	60	41	59,7	8	29	12,7	52	12	47
°	'	"																					
60	39	55																					
		1 44,7																					
		20																					
60	41	59,7																					
8	29	12,7																					
52	12	47																					
Latitude		52 12 47																					
<i>Capella</i> , Mean of the zenith distance taken on Jan. 16, 19, 26, Feb. 4, 5, 12, Refraction Error of line of collimation True zenith distance Declination in 1767 * Increase in 1,08 years Aberration, <i>Sun's Longitude</i> $10^s 10^o$ Nutation, <i>Moon's Node</i> $9 20$	6 7 $13\frac{1}{6}$	<table> <tr><th>°</th><th>'</th><th>"</th></tr> <tr><td>6</td><td>27</td><td>32,2</td></tr> <tr><td></td><td></td><td>6,5</td></tr> <tr><td></td><td></td><td>20</td></tr> <tr><td>6</td><td>27</td><td>58,7</td></tr> <tr><td>45</td><td>43</td><td>56,3</td></tr> <tr><td>52</td><td>11</td><td>55</td></tr> </table>	°	'	"	6	27	32,2			6,5			20	6	27	58,7	45	43	56,3	52	11	55
°	'	"																					
6	27	32,2																					
		6,5																					
		20																					
6	27	58,7																					
45	43	56,3																					
52	11	55																					
Latitude		52 11 55																					

* Flamsteed in his Britannic catalogue, p. 42, *Hist. Cœlest.* Vol. 3. gives the distance of Capella from the pole,

		Parts of 96	Degrees.
			° ' "
α Orionis,	Mean of the several zenith distances taken		
	on Jan. 16, 19, 26, Feb. 4, 5, 12,	47 6 10 $\frac{3}{8}$	44 50 42,5
	Refraction for altitude 45° 10' Barom. 29,88, Thermom. 39,2		59
	Error of line of collimation		20
	True zenith distance		44 52 01,5
	Declination in 1767	7° 20' 35",9	
	Increase in 1,08 years	+ 1,7	
	Aberration, Sun's Longitude 10° 10°	- 3,4	
	Nutation, Moon's Node 9 20	+ 2,9	
		Ap. decl. Jan. 30. 7 20 37,1	
	Latitude		52 12 38,6
Castor,	Mean of the zenith distances taken on March 18, 19, April 4,	21 1 1 $\frac{5}{8}$	19 49 5,2
	Refraction		21
	Error of line of collimation		20
	True zenith distance		19 49 46,2
	Declination in 1767	32° 22' 36",4	
	Decrease for 1,22 years	- 8,3	
	Aberration, Sun's Longitude 0° 0°	- 2,5	
	Nutation, Moon's Node 9 20	0,	
		Ap. decl. March 21 32 22 25,6	
	Latitude		52 12 11,8
Arcturus,	Mean of the zenith distances taken on May 7, 10, 11, 14, 15,	33 7 5 $\frac{3}{4}$	31 47 59,7
	Refraction for altitude 58° 12', Barom. 30,05, Therm. 54,8		35,1
	Error of line of collimation		20
	True zenith distance		31 48 54,8
	Declination in 1767	20° 24' 31",9	
	Decrease in 1,36 years	- 23,3	
	Aberration, Sun's Longitude 1° 20°	- 2,3	
	Nutation, Moon's Node 9 15	- 8,6	
		Ap. decl. May 10. 20 23 57,7	
	Latitude		52 12 52,5
α Aquilæ,	Mean of the zenith distances taken on July 10, 20, 28, Aug. 4, 5,	46 6 12 $\frac{7}{8}$	43 55 3,8
	Refraction for altitude 46° 5', Barom. 29,88, Thermom. 64,4		53,5
	Error of line of collimation		20
	True zenith distance		43 56 17,3
	Declination in 1767	8° 16' 3",8	
	Increase in 1,55 years	+ 13,	
	Aberration, Sun's Longitude 4° 0°	+ 4,2	
	Nutation, Moon's Node 9 10	+ 1,8	
		Ap. decl. July 22. 8 16 22,8	
	Latitude		52 12 40,1
	Latitude from observations of the sun		52 12 53
	the pole star		52 12 38,4
	3 circumpolar stars		52 12 25,4
	3 zenith stars		52 12 24,5
	8 other stars		52 12 40,1

pole, in the year 1690 = 44° 22' 5", and the decrease of that distance 7' 7" in the time that its longitude increases one degree, that is in 72 years, whence the declination in 1768

The declination computed from the <i>Connoissance</i> , &c. page 89.	45 45 37,5
From <i>De la Caille's</i> Ephemeris, 1765, &c. page lvii.	45 44 17,4
From Dr. Bradley. See tables belonging to Nautical Ephemeris for 1767, page 15.	45 44 12,9
	45 43 44,2

33. The longitude of Cambridge deduced from the observations made with the Hadley's quadrant. See page 33.

	Difference of Merid.			Longitude from Greenwich.		
	H.	M.	S.	D.	M.	S.
1767.						
Sept. 29. From the mean of 8 distances of the Moon, from β Capricorni	0	2	9	0	32	15 E
Oct. 4. From the third distance of the Moon from α Arietis, <i>singly</i>	0	0	27	0	6	45 E
Oct. 4. From the fourth distance of the Moon from α Arietis, <i>singly</i>	0	1	38½	0	24	37½ E
Oct. 4. From the mean of 3 distances of the Moon from β Capricorni	0	3	25	0	51	15 W
Oct. 9. From the mean of 8 distances of the Moon from Aldebaran	0	1	8	0	17	0 W
Oct. 11. From the mean of 6 distances of the Moon from the Sun	0	0	25	0	6	15 E
Nov. 28. From the mean of 5 distances of the Moon from the Sun	0	0	51	0	12	45 W
1768.						
April 22. From the mean of 6 distances of the Moon from the Sun	0	1	49	0	27	15 W
April 23. From the mean of 7 distances of the Moon from Aldebaran	0	2	11	0	32	45 E
April 23. From the mean of 9 distances of the Moon from Regulus	0	0	27	0	6	45 E
April 25. From the mean of 3 distances of the Moon from Pollux	0	0	14	0	3	30 E
April 25. From the mean of 6 distances of the Moon from Spica Virginis	0	2	27	0	36	45 E
Mean of the above deductions *	0	0	13¾	0	3	26¾ E

All these computations of the longitude (except the second) were made by Mr. Lyons.

34. The longitude was likewise computed from the 6th set of observations in Mr. *Dunthorne's* method by *W. L.* The following are the data.

Mean of 6 observed distances of the Moon's eastern from the Sun's western limb,	116	2	45
Index error of the quadrant to be subtracted	0	3	0
Mean of 6 observed zenith distances of the Moon's upper limb,	73	48	30
Mean of the several times of observation, Oct. 11th,	XXII	31	40
Sun's central transit, October 11th,	XXIII	48	27
From these data, the time of observation by the Sun	XXII	43	12
From the Nautical Ephemeris we have the semi-diameter of the Sun	0	16	6
Semi-diameter of the Moon	0	15	49
Moon's horizontal parallax	0	57	43
Computed altitude of the Sun's center	28	9	0
Refraction at that altitude	0	1	46
From the foregoing particulars we get			
The apparent distance of the centers of the Sun and Moon	116	31	40
Their reduced distance, by Mr. <i>Dunthorne's</i> method,	115	56	29
Whence, following the instructions at the end of the tables belonging to the Nautical Ephemeris, the longitude of Cambridge will be found 0° 3' 15" east of Greenwich.			
According to Mr. <i>Lyons</i> , the effect of refraction is	+ 0	3	22
Parallax	- 0	38	27
Reduced distance	115	56	35
Whence, following the instructions aforesaid, the longitude of Cambridge will be found 0° 6' 15" east of Greenwich.			

35. Those

* To the longitude so determined, should be added about 45" for the error of the transit telescope to the west.

In par. 41. is the determination of the longitude from two eclipses of Jupiter's satellites.

35. Those who compute this example in Mr. *Duntborne's* method, should remember, that the natural co-fines of angles above 90 are negative, and therefore the natural co-fine of the observed distance (in this case) is to be *added* to the natural co-fine of the difference of the apparent altitudes. See page 64, of the tables belonging to the Nautical Ephemeris.

36. These observations were made with a design to form some judgment of the usefulness of this method of finding the longitude at sea. Probably distances between the moon and stars cannot be taken so exactly at sea as these were, (to which the use of the stand hereafter described contributed much) and certainly the time computed from observed altitudes cannot be so near the truth as that shown directly by a fixed regulator; nevertheless the utility of the method may be inferred from these trials, in which the greatest difference from the mean is only $0^{\circ} 54' 42''$. According to Mr. *Maskeleyne*, the common reckoning at sea frequently errs five or six times as much as this. See *British Mariners guide*, p. 106. 110.

The other method by the watch is, no doubt, highly valuable. Neither of them perhaps hath yet attained all that perfection which some of their sanguine friends boast of; but if the latter of them were ever so perfect, it would not supersede the use of the former: probably both in their turns may be equally serviceable at sea; and both justly deserve that attention and encouragement the Board of Longitude has always given them. It may happen that sometimes one, sometimes the other of these methods only, can be put into practice. The watch may stand, or be out of order, or an observation of the moon's distance cannot be taken, although an altitude of the sun or stars may. But if both methods were equally practicable at all times, yet it would be very desirable to have both carried to all possible perfection, since in a matter of such moment, it must give great satisfaction to have the conclusions verified by the agreement of two methods so intirely independent on each other.

The other observations with Hadley's quadrant, in page 34, are partly vouchers for the error of the index when the distances of the moon were taken, partly trials of the quadrant in taking distances of the stars from each other, and in taking altitudes of the sun by reflection.

37. In these observations, if we take the mean of the six distances of Capella and Rigel to be $54^{\circ} 16' \frac{1}{2}$, and the index error $4' \frac{1}{2}$, their distance by the Hadley's quadrant in February 1768. will be $54^{\circ} 12'$. Now the difference of the right ascensions of these two stars is so small, that the difference of their meridian zenith distances may be taken for the apparent distance between them; whence their distance observed at the same time by the 18 inch quadrant was $54^{\circ} 11' 17''$.

38. Zenith distances of the Sun, taken by reflection from water with the Hadley's quadrant, compared with the same taken by the 18 inch quadrant, supposing the error of the line of collimation in the latter to be 20".

1768.			Had. Quad.			18 Inch Quad.		
			°	'	"	°	'	"
April 5,	Sun's	Lower limb	46	4	7,5	46	4	25,5
8		Upper limb	44	25	15	44	25	37
9		Upper limb	44	2	30	44	3	12
23		Lower limb	39	39	30	39	40	24
24		Lower limb	39	19	45	39	21	4

40. The difference between the quadrants in this last instance cannot be owing to the refraction of the glass planes that covered the water; for 1st, they were always set nearly perpendicular to the incident and reflected rays; 2dly, they were very truly ground parallel; 3d, had their surfaces not been parallel, turning the cover, end for end, must have discovered it; for then the incident and reflected rays, passing through contrary planes, their irregularities would have contrary effects, and if they had raised the object in one position of the cover, would have depressed it in the other.

40. The distances between Arcturus Lyra and α Aquilæ were taken with a design of examining whether Arcturus has a motion of his own among the fixed stars as has been suspected.* The following extracts from the observations of *Tycho Brahe*, *Hevelius*, and *Flamsteed*, will be of use in determining this point.

From *Tycho Brahe's* Historia Cœlestis

page				°	
39	1582. Feb. 23.	Inter Lyram & Aquilam	I	34	10
			II	34	8
			III	34	$8\frac{1}{3}$
			IV	34	$8\frac{2}{3}$
66	1583. Oct. 14.	Inter Arcturum & Vulturem	I	81	3
		His observationib. poteris fidere, erat	II	81	$3\frac{1}{2}$
		namque Cœlum bene serenum & tranquil.	III	81	$3\frac{1}{2}$
			IV	81	$3\frac{1}{2}$
		Inter Arcturum & Lyram per Port.	I	58	$48\frac{1}{2}$
			II	58	$48\frac{1}{2}$
			III	58	$48\frac{1}{2}$
	Oct. 15.	Inter Arcturum & Lucid. Vult.	I	81	$3\frac{1}{2}$
			II	81	$3\frac{1}{2}$
		Inter Arcturum & Lyram	I	58	$48\frac{2}{3}$
			II	58	$48\frac{1}{2}$
			III	58	$48\frac{1}{2}$

Per Q.
portat.
rectifi-
catum.

bonæ

per □
Portat.

From

* See a Letter from Dr. Bradley, Philos. Transf. N^o 485, for the year 1748. and *De la Lande's* Astronomy. Art. 2203. 2204.

From *Hevelius's Machina Cœlestis*, Vol. II.

page	Mens. Dies st. n.	Tempus sec. Horol. amb. Hor. Min. Sec.	Observationes	Distant. & Altitudines. Gr. Min. Sec.	Quo Instrumento.
54	1657. Nov. 22. <i>vesp.</i>	5 30 0 8 24 0	Lucida Aquilæ à Lucid. Lyræ Altitudo Lucidæ γ Orient.	34 11 40 52 51 0	Ost. M. Lign.* Quad. Az. †
82	1658. Sept. 11. <i>vesp.</i>	9 2 0	Lucida Lyræ, & Lucid. Aquilæ Rursus Denuo	34 11 40 34 11 40 34 11 40	Ost. M. L.
88	1658. Oct. 5. <i>vesp.</i>	9 5 30 10 1 0	Altitudo Capellæ Lucida Lyræ à Lucida Aquilæ Rursus	26 7 0 34 12 20 34 12 15	Quad. P. Or. ‡ Sext. M. O.
319	1661. May 29. <i>vesp.</i>	10 0 0	Arcturus & Lucida Lyræ Rursus Denuo	58 52 40 58 52 45 58 52 30	Sext. M. O.
427	1683. Sept. 19. <i>vesp.</i>	7 40 0	Lucida Aquilæ, & Lucida Lyræ Eadem distantia Altitudo Lucidæ Coronæ	34 12 20 34 12 35 54 16 40	Sext. M. O.

From *Flamsteed's Historia Cœlestis*, Vol. I.

page	1683. Styl. Vet. Maij 17.	Temp. App. H. M.		Dist. per lin. Diag. " "	Dist. per Coch. Revol. " "
60		10 41	Lyræ Lucida & Arcturus	58 55 35	58 55 36
61	1688. Jan. 31.	17 12	Lyræ Lucida & Arcturus	58 55 30	58 56 12

41. Two eclipses of Jupiter's satellites observed with a reflecting telescope of two feet focus, magnifying 50 times.

1768. April 21.	Emerfion of the second satelite, by the clock.	_____	H. M. S.
	Clock faster than the Sun	_____	VII 52 20
	Apparent time of observation	_____	2 45
	Apparent time at Greenwich by the Nautical Ephemeris	_____	VII 49 35
	Whence difference of meridians, Cambridge east of Greenwich	_____	VII 49 22
			13
May 11.	Emerfion of the first satelite by the clock	_____	XII 18 12
	Clock faster than the Sun	_____	40 1/2
	Apparent time of observation	_____	XII 17 31 1/2
	Apparent time at Greenwich by the Nautical Ephemeris	_____	XII 17 18
	Whence difference of meridians, Cambridge east of Greenwich	_____	13 1/2

To the difference of their meridians thus determined $3'' \frac{1}{2}$ should be added for the error of the meridian of Cambridge as shown by the transit telescope, (see the table, par. 15.) which makes the difference of their meridians $17''$, and the longitude of Cambridge $0^{\circ} 4' 15''$ east of Greenwich.

* i. e. Ostente magno ligneo. See *Hevelius's Mach. Cœlest.* Vol. I. page 132.

† i. e. Quadrante azimuthali. *Ibid.* page 149.

‡ i. e. Quadrante parvo orichalcico. *Ibid.* page 136.

|| i. e. Sextante magno orichalcico. *Ibid.* page 222.

DESCRIPTION OF A STAND

FOR AN

HADLEY'S QUADRANT.

42. **T**HE quadrant with which the observations on the moon, pag. 33, were taken is made of brass with perpendicular bars on the back-side*: it is 15 inches radius, and weighs 6 pounds. The difficulty of putting this quadrant into the plane of a great circle passing through the moon and star, and of holding it for any time in that position, made a stand necessary. Quadrants made of wood with a brass plate on the limb for the divisions, are lighter and fitter for sea. Much practice will enable seamen to hold properly such light quadrants by hand only; but it is not easy to prevail on those who are not under a necessity of learning to use this instrument, to take all that trouble. By means of the stand here described, a person not used to instruments may readily set any quadrant into the proper plane, and his attention will not be disturbed by the pain of holding an heavy instrument in an uneasy posture. †

Plate I. fig. 1. & 2. A A is a circular plate of mahogany 16 inches diameter; B B another circular plate $12\frac{1}{4}$ diameter, turning upon the former, and kept tight to it by the screw C. Fig. 3, is the plate B B seen flatwise, from above. On this plate is dove-tailed the standard board D; the grove into which it is dove-tailed, is represented in fig. 3. by d 1 & d 2. This standard board is supported by the bracket E, likewise dove-tailed into the plate B; its grove is seen in fig. 3. at e 1 & e 2. In fig. 1. e e are screws that fasten the standard board D to the bracket E. A square piece of mahogany G G, 3 inches in the side, and $1\frac{1}{8}$ thick, is screwed to F the center of the circular head of the standard board; to this piece G G, the circular plate H is dove-tailed at right angles. Fig. 4. represents the whole part G g, as seen edgewise from above; in this figure the dove-tailed grove in the plate H may be seen. The circular plate H is seen edgewise both in fig. 1. & fig. 4. but the perspective view in plate II. shows its circular shape. G g are two iron bars, screwed upon the edge of the

* See the note on par. 17.

† A stand for a common quadrant by which it may be set in the plane of the two objects whose distance is to be measured, is described in *De la Lande's Astronomy*, Article 2062, and delineated in fig. 169.

the square piece G (they are seen edgewise in fig. 1.) between these is screwed the leaden counterpoise K. The square piece of mahogany G, with all that is fastened to it, has a circular motion round the screw F, fig. 1. or L F, fig. 4. Against the round plate H, is screwed the flat board M M, 13 inches long, $3\frac{1}{2}$ wide, 0,4 thick, by means of a long screw N N, passing through the mahogany piece G, and the leaden counterpoise K. This board is seen edgewise in fig. 1. and flatwise in fig. 2. In fig. 4. may be seen the manner in which the screws N N, and L F pass by each other in the thickness of the mahogany piece G. This board M M with all that is fastened to it, has a circular motion round the screw N N. To the board M M are screwed two wooden collars P P, through which passes the iron axis Q Q, carrying a wooden arm R R, 13 inches long, $2\frac{1}{2}$ broad, 0,4 thick, seen edgewise fig. 2. and endwise fig. 1. At the end of the axis Q is a button screw to tighten it, so that the arm R R may be turned round upon this axis, and fastened in any position. At each end of the arm R R is screwed a brass head, seen flatwise in fig. 2. endwise in fig. 1. This brass head consists of two cheeks which spring together, and may be further drawn tight by the screw T; between these cheeks is lodged the cylindrical axis of the quadrant V V in fig. 5. The line V V, or common axis of these two cylinders passes through the center of gravity of the quadrant, and is parallel to the axis of the telescope, or axis of vision. In fig. 1. Y is a counterpoise to the quadrant, when lodged in the brass heads S S; Z is a bolt to fasten the arm R R when it is parallel to G g, (at right angles to the position in which it is drawn in fig. 1.) that is parallel to d d, in fig. 3. or to the plane of the standard board D. W is a pin in the board M; when this pin is brought to bear against the edge of the standard board D, the axis Q Q is then parallel to the plane of the standard board.

44. From this account of the construction of the stand we may observe, 1st, That when the quadrant is lodged in the brass heads S S, it has a small motion round the axis V V; it may be fixed by means of the screws T T. 2dly, The quadrant thus lodged has a motion intirely round upon the axis Q Q, being carried by the arm R R; it may be fixed by the screw Q. 3dly, This axis has a motion round the screw N N; the counterpoise Y balancing the quadrant, while the board M with its apparatus turns round N; it may be fixed in any position by the screw N 1. 4thly, The whole of this apparatus has a circular motion round the screw L F, it is balanced by the counterpoise K, and may be fixed by the screw L. Lastly, The standard board with all upon it, resting on the circular plate B, turns round the center of the great plate A, and may be fixed by the screw C.

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45. The method of using the stand is this: Having lodged the quadrant with its face upwards in the brass heads S S, set its plane nearly parallel to the plane of the arm R R, and fasten the screws T T. Turn the arm R R until it is parallel to G g, then fasten it by the bolt Z; bring the pin W to bear against the edge of the standard board D and fix the screw N 1, then releasing the screws L and C, turn the plate B circularly in azimuth, and raise the part G g in altitude, (round L F) till you see one of the objects through the telescope of the quadrant, and then fasten the screws L, C; unbolt now the arm R R, and release the screw N 1, this done turn the board M M round the center N N, and at the same time the arm R R round the axis Q Q till you see the other object through the telescope, and then fasten the screw N 1. The axis Q Q will now pass through the poles of the great circle drawn through the two objects, and if you turn the arm R R round that axis, you will see both objects successively through the telescope. The quadrant being now in the proper plane, and turning (by means of the axis Q Q) quite round in that plane, there will be no difficulty in setting the index so as to make the objects coincide. By releasing the screws T T and moving the quadrant a little round the cylindrical axis V V, the objects will appear in the telescope to pass each other in a direction perpendicular to the plane of the great circle drawn through them.

It may be convenient to raise the telescope so as to see wholly through the unsilvered part of the horizon glass, while you are setting the quadrant into the proper plane.

46. The face of the quadrant may be turned downward, and then lodged in the brass heads S S as before. In this position the object which before was seen directly will now be seen by reflection, and thus by means of these two positions, the faintest of the objects may always be seen directly, and the brightest by reflection. The operation for setting the quadrant into the proper plane is the same as before when the face was upwards, and it is equally easy to observe with it, whereas it is very difficult to hold a quadrant by hand in an inverted position. The inverted position is particularly useful in taking distances of the moon from stars west of her.

47. This stand may seem complicated, and has indeed a great variety of motions, yet fewer are not sufficient to set the quadrant (by any certain method) into the plane of a great circle passing through two given points, and at the same time to allow it a circular motion in that plane, quite round the poles of that circle.

48. The following observations may be of some use to those who intend to make a stand of this kind.

In

In all these circular motions, the contact is between brads and paper glued upon wood. Thus the plate A has a broad ring of brads screwed upon its upper face, and turned flat; the plate B has strong writing paper glued to its under face, these work against each other, and turn very smooth and free. The square piece G has a ring of brads rivetted upon that face of it which is next the standard board D; this ring is turned flat before the circular plate H is glued on the dove-tail: writing paper is glued on the standard board. The circular plate H has a ring of brads rivetted on it, which is turned from an arbor passing through an hole made for the screw N N after the circular plate H, and square piece G, are put together: to the board M writing paper is glued as before.

A round hole is sunk in the center of the square piece G, in which the head of the screw F buries itself, that the shank of the screw N N may pass by it.

49. The screws C, N N, and L F have no square part in their shank to prevent them from turning, but have each a steady pin put through their shank instead of the square; this steady pin being let into a slit made in the boards A, D, and H, respectively, prevents the shank of the screws from turning round with the nuts C, L, and N. The boards G and M have likewise a slit to let this pin pass through them.

The screw N N consists of two lengths meeting in n; their ends at n are each tapped; these ends enter into an hollow cylinder, tapped within, whose exterior shape is seen at n, fig. 1. thus the hollow screw connects the two parts that compose the whole length N N. If the hollow screw is turned round until it comes wholly on one part and leaves the other, then the two parts may be separated.

A piece of thick round brads is foldered to the counterpoise for the screw N 1, fig. 1. to bear against: The shank N n has a steady pin, which is let into a slit in this piece of brads, that the part N n may not turn round with the nut N 1.

The counterpoise K is thicker than the piece G, its thickness is $1\frac{3}{4}$ inches.

There is a springing plate screwed to each brads head S, against which the ends of the cylinder V V bear; it is not expressed in the figures.

50. The cylinder V and plate v v, fig. 5. are both cast in one piece. The plate v v is screwed against the face of the perpendicular bar at the back of the quadrant. Two holes X X, $\frac{1}{8}$ of an inch diameter are drilled through the perpendicular bars, so that the line X X may pass, either through, or just under the center of gravity of the quadrant, and be parallel to the axis of the telescope, or axis of vision; one plate v v with its cylinder being screwed on, an hole is drilled through that cylinder by a long drill passing through both the holes X X; the cylinder is then taken off and turned

turned on an arbor put through the hole so drilled. The other cylinder is then drilled and turned in like manner; by this means when both cylinders are screwed on to the perpendicular bars their axes will be in one right line.

Plate I. fig. 1. is the stand seen in the direction e_1, e_2 in fig. 3.

Fig. 2. is the stand seen in the direction d_1, d_2 in fig. 3.

Fig. 3. is the plate B B seen from above.

Fig. 4. is the part G g seen from above.

Fig. 5. shows the edges of the perpendicular bars on the backside of the quadrant, with the cylindrical axis $v v$.

Plate II. fig. 1. is a perspective view of the whole.

The stand here described is in the observatory at St. John's College in Cambridge.

D E S C R I P T I O N

O F A

T R A N S I T T E L E S C O P E M A D E O F T I N.

51. **T**H E first hint of making this instrument of tin, (that is iron plates tinned over) was taken from Mr. *M*, who observed that in this case, both the axis and the telescope might be of a conical form, with a base of almost any size; whereas if it were made of brass as usual, the axis only could have this form, and that with a very small base. This circumstance seemed a great advantage in point of strength, and it was plain that such an instrument would be both lighter and easier made than one of brass; wherefore I put this plan into execution, giving such dimensions to the parts, and making such additions as seemed likely to increase the strength, without greatly increasing the weight of the instrument. It was likewise necessary to contrive such a method of putting the whole together, that the form should be in every respect nearly true, so that it might be within the power of the screws that govern the wires to adjust them perfectly.

52. I shall here give a short description of the whole instrument when put together.

In plate III. fig. 1. *A B C D*, is the axis of the whole instrument composed of two frustums of cones soldered together at their bases *A B*.

E C F D are solid pieces of bell metal for the centers; the part *D F C* is within the tin cone; the part *E D C* is cylindrical and without it: on this part the whole instrument turns as usual.

M I L are *Mitre-pieces*. These are first made frustums of a cone, the lesser base being *M M*, the greater base equal to *A B*, and then cut away so as to fit the middle of the axis; this will give them the shape of a mitre whose bottom is *M M*, and point *L*.

M M, *N N*, are frustums of cones soldered upon the mitre-pieces, which compose part of the telescope.

N N, *P P*, A cylindrical part at each end of the telescope-cones, one of which *O n*, contains the object glass, the other *Q n*, the eyeglass and cross wires.

53. The process of making a transit telescope of tin is thus,

All the pieces of tin for the several parts must be at first cut out somewhat larger than their true size, and, being tackt together in pairs, be well planished: The pieces must then be separated, and cut exactly to their true shape described in par. 63. after which proceed as follows:

54. Turn

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54. *Turn up** and folder the cones for the axis A B C D. *Rough turn* in the lathe, the solid pieces of bell-metal for the centers † making the part D F C fit the inside of the cone exactly, and then they will fit steady and their axes coincide with that of the cone. The cylindrical part should fit tight into the tin, or rather should force it open a little. Having first *tinned* the surface of the bell-metal pieces all over, folder them into the cones, making the folder soak quite through between the tin and the bell-metal, this will indeed unfold the seam of the tin cone as far as D F, but the other part of the seam will hold it together until the folder in this part is set, which will then bind all fast.

55. *Set down* the bases of the cones all round their edge, making a small part ($\frac{1}{8}$ th of an inch) cylindrical, or rather conical the contrary way, as in fig. 2. which is a section of the cones to their full size; A a and B b represent the parts set down so as to taper a little contrariwise to the body of the cone. The tin will spring so that one cone may be forced into the other at their bases A B, A B fig. 2. and then their form will keep them fast together even without folder. Divide the circumference of each cone into four equal parts, beginning with the seam, and through the points of division, draw lines along the sides (accounting the seam for one) perpendicular to the circumference of the base. Force the cones together, putting their seams on contrary sides not to join. ‡ Mark, with a strong point, the junction of each of those two lines drawn on the cones where there is no seam. Through these points the axis of the telescope must pass, and also the axis of a cylinder H h, which is to be put through the cones. On these points, as a center, with a radius equal to that of the cylinder H, describe a circle, and likewise another within it with a radius $\frac{1}{8}$ inch less than the former. The cones must then be taken asunder, the inner circle cut out, and the tin turned up square as far as the outer circle, so as to close against the cylinder which passes through the axis, as is expressed in fig. 3. where h h shows the part so turned up. ||

56. Make

* Bending the tin plate round a *bec iron* into a conical or cylindrical form, is called *turning it up*. Bending some part of a flat plate outward, is very frequently called, *turning it up*. To *set it down*, generally means to bend it inwards.

† Drill the center holes, by which the bell-metal pieces are turned, deep and true.

‡ For if both seams are on one side, the axis will not be in equilibrio in every position.

|| There is a necessity of perforating the double cone C C D D through the middle A B, at right angles to its axis E E, because of seeing through the telescope. A meer hole would weaken the junction of the cones by diminishing the seam, therefore a cylinder H is put through this perforation which can be foldered to the edges of the cones all round: but in tin, no joint is strong which has only edge against surface; it,

56. Make now four *diaphragms* of tin, these are circular tin plates, whose edges are turned up to fit the inside of the cone, their sections are expressed in their places at G, fig. 1. and one of them separately at fig. 4. They serve to keep the sides of the cone from being forced in or out. To keep the cones exactly circular, turn an hole either in hard wood or metal to fit their outside just where the diaphragms are to be placed; force the cones into this hole while you folder the diaphragms within them. If the diaphragms do not exactly fit the inside of the cones, fill up the intervals with folder, and when the folder is set, these diaphragms will preserve the form of the cones as well as strengthen their sides. Force together a second time the cones which compose the axis A B C D, putting their seams exactly opposite, by means of the lines drawn on their surface. Put now the whole axis, thus set together, into the lathe, applying the center points of the puppet-heads to the holes from which the bell-metal pieces C D E F were at first turned; see if the axis runs true in the lathe, if not, by striking on the seam A B, so as to shift the parts of the joint, you may easily set it true, so that the two cones which compose this part shall have one common axis. Tack the joint with folder in five or six places while it is in the lathe, then take it out and folder the joint compleatly. You may now, with a bec-iron make the holes round, through which the cylinder H is to pass, being careful not to use much force, for fear of disturbing the joint; then make the cylinder H to fit the holes and folder it in.

58. Prepare the mitre-pieces, which being cut out as described par. 63. must be turned up and foldered, whereby they will become frustums of a cone; the diameter of their lesser base being M M, that of their greater base equal to A B, and their height L m, fig. 1, and 3. Divide the circumference of the frustums into four equal parts, beginning with the seam, and through the points of division draw lines perpendicular to their base; the frustums must then be cut so as to fit the double cone or axis A B C D, and sit steady thereon, the two opposite lines where there is no seam, corresponding to and joining with the like lines on the axis: the points of the mitre (in one of which is the seam) just reaching to, and meeting at right angles, the seam of the axis. The seams of the two mitre pieces must be on opposite sides of the axis, not joining or running into each other for the reason given before. (See note par. 55.) The edges of the mitres at I, must be turned up to fit the surface of the axis, the part so turned up being about $\frac{1}{8}$ of an inch at I, and diminishing gradually to nothing at the point L. (See note par. 55.) This is expressed at I, in fig. 3.

The
it should have surface against surface, as in all common seams where one part laps over the other. Therefore a small part of the tin must be raised up, out of the cones, to fit close to the cylinder which passes through them.

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The correspondence of the lines drawn on the mitres with those on the axis, will be a means of setting these mitre-pieces true, so that their common axis shall pass through E E, correspond with the axis of the cylinder H, and be at right angles to E E, the axis of the instrument; in this position the mitre pieces must be foldered. As the mitre pieces are very tender, to keep them exactly round, it will be proper to turn a piece of wood with a rabbet just to fit their end M M. The section of this piece of wood is expressed in fig. 5, in which m m is the rabbet that fits tight into M M, fig. 3. This *stopper* is to be put into the mitre-piece while it is foldering on the outside along I L, fig. 3. After it is foldered on the outside, a large body of folder should be lodged on the inside of the seam I L, between the mitre and axis of the instrument, which will strengthen this axis very much. You will find the whole thus put together exceeding stiff and strong, owing partly to its conical form, partly to the diaphragms, cylinder and mitre-pieces. The inside of the cylinder must be now black-varnished, * and then the whole put into the lathe, and the cylinders E D C turned over again, that they may have one common axis. They must likewise be ground to make them perfectly round and of a size; the process for which, being the same as is commonly used in other transit instruments, need not here be particularly described. †

59. The

* Before the cylinders E D C are finished, lest the heat used in laying on the varnish should alter the shape of the axis. A round iron made hot and held within the cylinder will warm it sufficiently to take the varnish.

† The cylinders may be ground by two strong half collars of brass, (about $\frac{3}{8}$ of an inch broad,) screwed together so as to form an intire collar to fit the cylinder. As the cylinder wears less, these half collars are to be screwed closer. The proper powder for grinding is pumice stone scraped or powdered; emery, which cuts faster, is apt to stick in the bell-metal, so as to make the cylinders, (after they are ground with it) wear the parts on which they turn. The powdered pumice must be mixed with water, and laid upon the cylinder by very small quantities at a time: the collar is then to be put over it, and the cylinder ground true by turning the collar round, and at the same time drawing it endwise. The whole operation should be performed by hand only, and not in the lathe. It is easy to feel the prominent parts of the cylinder, which, if considerable, must be taken down in the lathe, for the less there is left to be done by grinding the better.

Instead of two half collars of brass, a round hole may be punched in a square piece of copper ($\frac{1}{4}$ of an inch thick, and $1\frac{1}{4}$ in the side) and the cylinders ground with this. As the hole wears it may be closed up by hammering the copper on the edge, or a fresh piece may be punched; for an hole may be easily punched though not drilled through copper.

Copper holds the cutting powders better, and grinds quicker than brass, and an hole so made will grind the cylinder truer than two half collars screwed together, for it will yield less to the irregularities of the cylinder. It is not necessary that this hole should be exactly round, though it may easily be made true by a round broach.

59. The bell-metal cylinders being finished, you must now turn up and folder the two telescope cones M M N N, and the cylinders N N P P. Within the end N N of each cylinder, folder a ring of brass wire, to prevent the cells which contain the glasses from being pushed into the conical part of the telescope. The cylinder P P N N goes within the cone N N M M, the end of which is made cylindrical for about a quarter of an inch, that the joint may hold the better.† You must have two stoppers, like that before described fig. 5. turned on an arbor so as to have an hole exactly in their middle. One of the stoppers is to fit the greater end of the telescope-cone M M, the other to fit the end of the cylinder P P; by means of these, you may put the part M M P P into the lathe, and set the joint N N so that the whole shall run true, in the same manner as the cones composing the axis were set; thus the cone M M, and cylinder P P will be made to have one common axis; when they are set true, tack and folder the joint N N in the manner before described par. 56. The seam of the cone and cylinder must correspond.

60. Prepare four diaphragms g g, two for each telescope-cone; these diaphragms must be perforated, the aperture of that next the object glass must be of the same size therewith; the aperture of that next the cross wires rather bigger than the aperture of the frame which holds those wires. The aperture of the two intermediate ones of a middle size between the others, so as to exclude all foreign light, and admit all that comes from the object: The diaphragms must be foldered within the telescope-cones in the manner before described for those in the axis; (par. 56.) they must likewise be black varnished, either before or after they are foldered in.

61. The two telescope-cones with their cylinders being thus finished, you may now folder one of them, P Q P M M, upon its mitre-piece M M, making the seams to correspond. To set this on true, you must have two stoppers as before, (par. 59.) one to fit the end of the cylinder P Q P, the other to fit the contrary mitre-piece M m M; by means of these stoppers the part of the instrument Q E m E Q may be put into the lathe, and examined by turning it round the axis Q m. The joint M M may then be set true as before, (par. 56.) which may be easily known by trying whether the two center holes of the axis E E, pass the same point of the *rest* of the lathe; for then the axis Q m will be exactly at right angles to the axis E E. Lastly, the other telescope-cone, with its cylinder, is to be foldered upon the other mitre-piece M m M. To set this joint true, you must again have two stoppers to fit the two ends of the cylinders P Q P, P O P, by means of these the whole instrument may be put into the

† See note, par. 55.

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lathe, and turned round the axis QO : The joint $M m M$ may then be set true, so that the center holes $E E$ shall both pass the same point of the rest of the lathe, and then the axis of the telescope will be exactly at right angles to the axis $E E$, on which the whole instrument is to turn.

There is no danger that the heat of the tin, in foldering the joints M, M , should alter the truth of the axis $E E$, as would be the case, if the telescope-cones were to be foldered upon the cones of the axis without the intervention of the mitre-pieces.

It will be easy for those who have no lathe, to make an extempore apparatus to answer the purpose of a lathe in setting the several joints true, as strength is not required in this business.

62. I shall now give some account of the tin proper to be used.

Tin plates differ very much, according to the nature of the iron whereof they are made. The best are those made of a soft iron and that are of an even thickness and temper; for these will become elastic by hammering, and yet work into a regular shape.

The sizes and weight of common tin plates.

Sort	Breadth, Inches.	Length, Inches.	Weight, oz.	Wt. per foot. oz.
1	12	17	27	19
2	12	17	$20\frac{1}{2}$	$14\frac{1}{2}$
3	12	16	16	12
4	12	16	14	$10\frac{1}{2}$
5	11	15	10	$8\frac{3}{4}$
6	$10\frac{1}{4}$	14	9	$8\frac{1}{3}$

The transit telescope here described was made of plates of the third sort.* It took four plates of tin, and two days and an half's work of the tinman. When finished, its weight (without the glasses) was three pounds; one of brass of the same size, made in the usual manner, would weigh at least twelve pounds.

63. With the center A , and radii $A R, A r$, (fig. 6.) describe two arches of a circle $R R$, and $r r$, draw the radii $A R, A r$, and the intercepted figure $R R r r$ is the form of the pieces of tin out of which the frustums of cones, both for the axis and telescope are to be made; to it must be added a small part terminated by $p q$ parallel to $R r$, for the lap of the seam.

Let the greater diameter of the conical frustum for the axis, namely $A B$,

* One whose axis was 24 inches, and telescope 50 inches long, was made of the second sort of tin.

A B, fig. 1. = 3,5 inches, the lesser diameter C D = 0,6, the slant side A D = 9, then is A R in fig. 6. = 10,862, A r = 1,862, R R = 10,532, and half the angle R A R = 29° .

The greater diameter of the conical frustums out of which the mitre-pieces are to be made, must be equal to that of the conical frustums out of which the axis was made, that is 3,5 inches. Let now the whole slant side (both of the mitre-pieces and the cones,) L n, fig. 1. = 13,5 inches; the lesser diameter N N = 1,2, the slant of the mitre-piece only, L m = 3; then A R, fig. 6, = 20,543, A r = 17,543, R R = 10,864, and half the angle, R A R = $15^{\circ} 20'$.

For the telescope-cones M M N N, fig. 1. we have A R, fig. 6. = 17,543, A r = 7,04, R R = 9,28, $\frac{1}{2}$ R A R = $15^{\circ} 20'$ as before. Observe, that the seam R r p q, should be left rather larger in cutting out these parts than in others, because allowance is to be made for the thickness of the tin, that these cones may go over the mitre-pieces: Another circle with the center A, and radius greater than A R by $\frac{1}{8}$ of an inch should be struck to allow for the lap of these cones upon the mitre-pieces.

The diameter of the cylinder H h should be equal to or rather greater than N N, its length about $\frac{1}{2}$ an inch more than A B.

64. The computation of the sizes of these several parts depend on the following theorems: Put D = the greater diameter of the frustum; d = the lesser diameter; S = the slant height.

Then $\frac{S}{D-d} \times D$ is the radius of the greater sector R A R in fig. 6. Call this R, and R — S is equal to the radius of the lesser sector or A r in fig. 6.

Divide 90 degrees by $\frac{S}{D-d}$ and it gives the semi-angle of the sector or $\frac{1}{2}$ R A R, whose sine, (to radius R) doubled, is the chord of that sector, or R R in fig. 6.

65. The construction of the eye tube, and disposition of the glasses therein is shown in fig. 7. where a a, a a is the tin tube (or part Q n in fig. 1.) marked by a strong black line; a b, a b is a brass tube within it at the end of which is the sliding frame c c that carries the cross wires; d d d d is the perforation through both the sliding frame and end of the brass tube. At e is the dove-tail, in the middle of which is the screwed hole for the regulating screw. f is a notch cut in the side of the brass tube, having another of the same shape opposite to it; the key f f, fig. 8. fits into these two notches, by means of which the tube can be either drawn out, pushed in, or turned round.* Figure 9 is the sliding frame and

* If the sides of the tube be very thin, a piece of thicker brass may be soft soldered within it, just at the place of the notch, to give the key better hold.

and cross wires, as seen by the eye placed at the center of the object glass, a a a a is the tin tube, s s the regulating screws ; they pass through an oblong hole in the tin tube, in order to allow a small circular motion of the brass tube within the tin one round their common axis, for adjusting the vertical wires : † t t are two pieces of brass interposed between the heads of the regulating screws and the tin tube, to give a larger bearing to these screws, and to cover the oblong hole. v is the section of a piece of brass $\frac{3}{4}$ inch long, foldered on the outside of the tin tube, parallel to its axis ; and a quarter of a circle distant from the regulating screws. In fig. 7. g g, g g, is a brass tube sliding upon the tin tube, having a notch at the top to receive the brass piece marked v fig. 9 ; this construction allows the tube g g g g to be drawn out or pushed in, (to make the telescope distinct) but prevents its being turned round. Notches are cut on the side of this tube, to receive the pieces t t in fig. 9, so that its motion may not disturb the frame with the cross wire. At the end of the tube g g, fig. 7, is a short cylindrical part having a screw cut both on the inside and on the outside. On the inside is screwed the cell in which the eye-glass is set, on the outside is screwed the tube b h, b h. Upon the tube b h, slides the tube m m m, that carries the reflecting metal ; this metal is foldered to a piece of brass and fastened to the plate at the end of the tube m m by 4 screws, one in the middle that draws, and three at the circumference that push. o o is a circular plate, foldered to the outside of the tube m m ; two dove-tailed cheeks are screwed upon this plate, between which slides a brass frame carrying two pieces of glass whose inward sides are smoaked for looking at the sun.* The tube m m m turns round upon the tube b h, which has four holes in its sides, a quarter of the circle distant from each other, which correspond to the eye hole in the circular plate o o, so that by turning the tube m m you may look into the telescope four ways ; two in the direction of the axis E E, fig. 1. and the two other at right angles to the former ; the two last are most convenient for general use, one for the northern, the other for the southern part of the meridian. Such a *side-glass* makes it very easy to take transits in any part of meridian, and intirely supercedes the use of an observing stool to lie upon, which would otherwise be necessary for observing stars near the zenith. There is likewise another eye-tube, having an hole to look in at the end, which may be put on instead of the tube m m, but it is never used except in adjusting the cross wires : As the

† See *De la Lande's Astronomy*, Article 2089.

* Smoaked glasses are vastly preferable to any coloured glass, which indeed is almost out of use. The foot will shake off, but when this happens they are easily smoaked again, one end should be done very lightly, and then gradually darker and darker to the other end. See *De la Lande's Astronomy*, Art. 1987. 1989.

the telescope must be frequently reversed in that work, it saves the trouble of turning the side-glass every time.

66. The innermost circle in fig. 9. is the size of the image of the sun in this telescope, and the distance between the vertical wires are each $\frac{2}{3}$ of the diameter of that image. The mean time of the sun's passage over the meridian is $2' 15''$, therefore the intervals between the successive appulses of the sun's western and eastern limb to these three wires will be $90''$, $45''$, $45''$, $45''$, $90''$; and the order of those appulses is as follows, 1st, the western limb to the first wire; 2dly, the same limb to the second wire; 3dly, the eastern limb to the first wire; 4thly, the western limb to the third wire; 5thly, the eastern limb to the second wire; 6thly, the same limb to the third wire. The distance between the outside wires and the edge of the field, or $r d$ in fig. 9. is a semi-diameter of the sun's image; so that the sun enters the telescope $1' 7\frac{1}{2}''$ before it touches the first wire.

Had the distances between the wires been each $\frac{1}{3}$ of the diameter of the sun's image, the intervals of the appulses would have been all equal to $45''$, and the western limb would have passed all the wires before the first appulse of the eastern limb. If the distances between the wires had been $\frac{4}{9}$ of that diameter, the intervals of the appulses would have been $60''$, $60''$, $15''$, $60''$, $60''$, and their order, as in the last case, not intermixt; but the first disposition of the wires gives the most time for taking meridian zenith distances of the stars by the quadrant, and makes none of the intervals very short in the transit of the sun. It is difficult to make the distances between the wires precisely equal, but there seems to be no absolute necessity for it, as the angle which these distances subtend at the object glass, can be exactly ascertained by the transits of stars over the wires.

The focal distance of the object glass of this telescope is 30,5 inches, that of the eye glass 1,37; it magnifies 22 times.

67. It will not be improper to add here, the construction of the eye tube of the transit telescope in the observatory.

In this then are four tubes, the principal of which $a a$, $a a$, (plate VI. fig. 4.) marked by a strong black line, is the tube of the telescope itself, and carries the object glass at one end; within this at the other end is a short tube $b b$, carrying the sliding frame with the cross wires, whose perforation is $d d$. This frame is made in a different manner from that before described. In that, the frame was an intire circle, and the dove-tail below it in another plane, in this, two segments are cut off from the circle slantwise, so as to form the dove-tail by being screwed to the plate $d d$ foldered at the end of the tube $b b$; between these segments slides the other part of the frame which carries the wires. $d d$ is the perforation of the

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the frame, *e* is the screwed hole of the regulating screw. This frame and wires, as seen from the eye-end of the telescope, is represented in fig. 5. To draw the tube *b b* out of *a a*, two small holes are tapped in the plate foldered at the end of that tube near its circumference, into either of which may be screwed an hooked wire, to draw the tube out withal; within the tube *b b* slides another *p p*, carrying one of the eye glasses *set* in a brass cell, which is screwed into a circular plate at the end of *p p*. Over *a a* slides the tube *g g*, *g g*, at the end of which is foldered the lesser tube *h h*, upon *h h* slides the tube *m m*, carrying the reflecting metal as before; in the side of this tube is another eye-glass. This part as seen endwise, is represented in fig. 6, where *m m* is the section of the tube *m m* in fig. 4; upon this tube is foldered the part *t t*, which is a circular plate with a short cylindrical tube joined to it; this short tube is filed so as to fit upon the tube *m m*; the under surface of the circular plate just resting upon the tube *m m*, and touching the top thereof in a line parallel to its axis. Upon this part *t t* is screwed the circular plate *v v*, having a small cylindrical part which just enters into the hollow cylinder *t t*; within this is screwed the cell in which the other eye glass is set. *s s* are the screws which fasten the plate *v v* to *t t*; *o o* are the dove-tailed segments between which slides the frame carrying the smoked glasses. The tube *m m* both turns round and also slides upon the tube *h h*, the former motion serves to direct the side-view to any quarter as before, the latter to adjust the telescope to distinct vision.

The tube *p p* slides within *b b* to adjust the lens it carries, to a proper distance from the other eye glass, so that the telescope may be free from colours. When all these parts are adjusted, the four tubes, *g g*, *a a*, *b b*, *p p*, must be pin'd together, with small pins fitted in very tight, whose heads are on the outside of the tube *g g*, otherwise the motion of the tube *m m* upon *h h* *g g* might disturb the regulating screws, and the frame that holds the cross wires.

The focal distance of the eye glass *p p* is 2,54 inches, that of the other eye glass *o, o*, and the eye must be got as close to it as possible; both these eye glasses are plano-convex, having their plane sides towards the eye. The focal distance of the object glass is 42,2 inches. The distance between the object glass and eye glass *p p* is 40,45 inches; from *p p* to the cross wires is 1,04 inches: * The telescope magnifies 28 times.

68. The

* When the telescope was first made, this distance was so small that the dust and scratches upon the lens *p p* were visible through the first lens along with the wires, and appeared like moths on the object; a fault that should be guarded against in all telescopes.

68. The manner of illuminating the cross wires in this telescope that they may be seen in the night, is by an *illuminator* or night-vane as usual. The stem carrying the vane is screwed to a tube which slides on the outside of the object end of the telescope, so that it may either be drawn backwards or forwards or turned round. The vane-plate may likewise be set to any inclination. This plate is brass, to which white paper may be fastened by sealing wax, thus; warm the plate till it will just melt the wax, with which cover the plate all over, then lay on the white paper; put a loose paper upon this, that it may not be soiled, and press all close with a warm smoothing-iron. If the colour of the wax should appear through, another paper may be pasted to that which is waxed on. If the sealing wax is to be taken off the brass again, melt off the gross part, and then while the plate is warm a little spirit of wine will wash the remains clean off.

69. Fig. 1 & 2. plate IV. is the apparatus for carrying the lamp to illuminate the cross wires. In fig. 1. it is seen on the north side; the telescope being directed to the zenith: In fig. 2. it is seen on the west side, the telescope being inclined to the horizon in an angle of 45° . a A a is the axis of the whole instrument, T T is the telescope part, S the night-vane at the end of it. B b a round axis of wood passing through a wooden frame C C, seen edgewise in fig. 1. It is represented as having one end broken off, but that end is like the other, and the whole stands on the top of one of the pillars between which the telescope plays. d d is an arm of wood $\frac{1}{2}$ inch thick, and 3 inches broad, seen edgewise in fig. 1. and flatwise in fig. 2. It is braced behind to the wooden axis, but this brace is omitted in the figure. At e e is a pin on which the lantern L hangs, with the lamp F therein. The lantern turns freely upon the pin e e, and always hangs down perpendicularly. D is a counterpoise to the lamp, screwed to the end of the arm d d. The part e F, fig. 2. is made equal to A B, and the part B e to A S. By this means, the flame F describes a circle whose radius is A S, fig. 1. round the axis of the telescope a A a, although the apparatus that carries the lamp turns round another axis B b. The lamp therefore may be set exactly against the vane in any position of the telescope, and the axis of the telescope a A a, will not be encompassed with any work that will obstruct the lifting of it out of the supporters, or the hanging on of the level.

70. The lamp being taken off, an oblong plate of tin, of the exact weight of the lamp, may be put upon the pin e e, by means of two loops soldered to the tin. This plate shades the instrument from the heat of the sun by day; it has an hole in the middle to admit the sun into the telescope; a short tube is soldered over the hole, so that the sun cannot shine obliquely through it upon the axis of the instrument.

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71. The telescopes here described are made with compound object glasses, though they seem in nowise necessary for such instruments. The compound object glass is indeed a most valuable improvement in telescopes, intended for discovering the minute parts of an object; but for transit instruments and quadrants it is not only unnecessary, but there are even objections against it. One great advantage of the compound object glass is, that it will bear a larger aperture, and consequently admit more light than a common one, but this is never wanted for viewing the sun or stars which are bright enough to be seen with a very small aperture. In looking at the sun the aperture of a common object glass may be contracted enough to make the image very distinct, and yet admit sufficient light. A large aperture has indeed been thought to contribute to the seeing of the smaller stars in the day time, but I believe this is a mistake; it is not *aperture*, but *magnifying power*, that is most likely to effect this *desideratum* in astronomy. The aperture of the transit telescope in the observatory has been sometimes reduced to half its usual size, and yet such stars could always be seen with it so reduced, as could be seen with it when of the full size: On the contrary, small stars were seen with the transit telescope (magnifying 28 times) which could not be seen with the quadrant-telescope, (magnifying 18 times;) when the apertures of both telescopes were reduced to the same size; and stars may be easily seen in the quadrant-telescope, which are not visible to the naked eye.*

72. The

* *Hooke* says, that on the 21st of October, 1669, at 17 minutes after three o'clock, the sun then shining very clear into his room, he observed the bright star in the *Dragon's* head to pass by the zenith as distinctly and clearly as if the sun had been set, but without that glaring brightness and magnitude it was wont to have in the night: And says he found the like divers other days before. See *Hooke's* attempt to prove the motion of the earth, page 25.

The star which *Hooke* thus saw was undoubtedly γ *Draconis* a star of the third magnitude only, but the telescope he made use of was 36 feet long, and probably magnified 120 times; its aperture, if we may guess from the practice of the times he lived in, was hardly more than $3\frac{1}{2}$ inches.

The same star was observed throughout the whole year by Dr. *Bradley* with a telescope only $12\frac{1}{2}$ feet long; such a one might probably magnify 70 times. See *Philosophical Transactions*, N^o 406.

It may yet seem strange, and contrary to established rules, that enlarging the aperture should not contribute to make the stars visible in the day time, and that increasing the magnifying power should: I will hazard a conjecture of the cause of this, for the sake of those who are unwilling to credit a fact, unless they can assign a *reason* for it. By a common rule in optics, the brightness of any object seen through a telescope is diminished by increasing the magnifying power, because the brightness of the picture upon the retina is as its area inversely, (*Smith*, art. 348.) If the linear dimensions of this picture are enlarged by increasing the magnifying power of the telescope, its light will be diluted by being spread over a larger area, and thus the picture becomes darker;

72. Another advantage of the compound object glass is diminishing the length of the telescope; but this will be a disadvantage here, unless finer wires (to be placed in the focus) can be procured than any hitherto made. For all that part of the object, which corresponds to so much of the image as is occupied by the wire, will be hid by it. The part of the object covered by the wire therefore depends on the absolute magnitude of the image, and will be greater when the focus of the object glass is shorter. And this is a great disadvantage, both in transit and quadrant-telescopes: for the transits taken by one and the angles by the other must be uncertain when the star is hid behind the wire.

73. But there are also objections to the use of compound object glasses in these instruments: For as these glasses must be *set* in a cell and screwed into the springing tube put within the telescope, there is some danger that this screw should get loose. If this springing tube and the other parts of the work are not made very true, (so that the common axis of the two lenses, whereof the object glass is compounded, may perfectly coincide with the axis of the eye glasses) the image will be less distinct than that of a common telescope: for which reason it is best in these telescopes to have every part fixed, and then if the maker adjusts the glasses properly at first they will always remain so: A very nice adjustment of the common axis of all the glasses can hardly be preserved, if liberty is allowed for drawing the object glass backwards and forwards, or turning it round; the former of which is necessary to adjust its distance from the cross wires, and the latter may be necessary if the object glass is not nicely centered, or the brass work not exactly round. These objections indeed rather show that greater nicety, or perhaps a different construction of the brass work, is necessary, than that such glasses cannot be advantageously applied to these instruments. However those workmen who are not well acquainted with the nature of compound glasses had better in all cases be content with common ones: such persons can get no advantage to themselves by meddling; and their unskilful attempts may discredit a most useful discovery, and injure the reputation of the ingenious inventor.

74. The darker; therefore, to keep the same brightness, the aperture of the object glass must likewise be enlarged so as to increase proportionably the quantity of light admitted through it: And on this is founded the old rule for adjusting the focal lengths and apertures of telescopes: But the picture of a star, which subtends no visible angle, hath no linear dimensions, nor is its area enlarged, or its light diluted by increasing the magnifying power. On the contrary, the picture of the azure sky, which surrounds the star, and fills up the field, becomes fainter by this means, agreeably to the common rule; and as the circumambient sky seen through the telescope grows darker, the star itself is sooner discovered upon it.

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74. The construction in fig. 4. with two eye glasses, enlarges the field, and makes the outsides of it distincter than the old construction with one eye glass; but this likewise seems unnecessary in these instruments. For in transit-telescopes and quadrants the observation is always made when the object is in the middle of the field, or near it; nor is great distinctness in stars either attainable or necessary: As to a large field it is not wanted, for in a transit-telescope the object can always be found without difficulty by the index and clock; and in a quadrant by setting the telescope to the supposed altitude; besides, this construction with two eye glasses is complex, diminishes the size of the image (the focus of the object glass being the same) and therefore requires finer wires; * it hardly admits of a side glass, and is liable to be disturbed by any change in the center of the eye glass p p, which will alter the place of the image on the wires, so that on the whole I believe we must at last (in these instruments) stick to the old construction of telescopes with two simple lenses only.

75. In one telescope I placed a plano-convex lens in the focus of the object glass, and on the plane side had lines drawn with a diamond, which were *cuts*, not *scratches*; these were finer than any wire, and suited land objects very well, but not the sun, whose light was so refracted by the sides of the cleft or cut, that the lines neither appeared black nor well defined, and the heat opened the cleft a little. It was besides liable to the objection of having all the dust on the glass visible, otherwise this construction had the advantage of increasing the field without diminishing the image, and lines so drawn on glass are not subject to be disordered or broken as wires are.

The transit telescope made of tin, before described, is in the possession of Mr. *Nairne*, near the Royal Exchange.

* See before, par. 72.

D E S C R I P T I O N

O F A

P E N D U L U M WITH A W O O D E N R O D.

76. **T**H E rod of this pendulum is made of straight grained yellow deal, neither the sort which is very white and spongy, nor that which is red and of a strong grain. This rod is a cylinder $\frac{5}{8}$ of an inch diameter, and 42 inches long: it should be painted and gilt, and if it were also varnished would be still less subject to changes from moist weather.

77. The rod being first *roughed out*, a brass ferril (a, fig. 4. plate V.) must be drove on its lower end turned on purpose to receive it. The rod is then to be put into the lathe, the ferril turned true, and a few other places in the rod may be likewise made round; the whole is afterwards to be made smooth, straight and round by an hollow plane. An extempore collar of wood must be fixed to the lathe in which the ferril may run, while the other end of the rod bears against the center point in the puppet head; an hole is then to be turned or rather drilled at the bottom of the rod along the axis to receive the steel wire b. This wire must be turned, the upper part which goes into the rod a little taper, and rather bigger than the hole in the end of the rod, the rest of the wire cylindrical and the end b conical. A screw must be cut upon the cylindrical part with *stocks*. The wire must be forced into the hole at the bottom of the rod, and then cross-pinned at p through both ferril and rod.

78. The top of the rod, fig. 1. is slit along the grain, with a fine spring saw, to receive the spring by which the pendulum is suspended; the two parts are forced together, and made to pinch the spring, by the screw a a, which passes through a quarter part of a brass ferril b, and is tapped into the opposite quarter part c.* This screw (as well as the others about the pendulum) is made with a square at the head, and is turned with a key.† The spring is a piece of strong watch spring, which has never been coiled up; to the upper part of it are rivetted two brass cylinders or buttons, opposite to each other, one of these is seen at a in fig. 2. These bear the weight of the pendulum for a while, during the time it is suspending, as will be shown par. 85.

79. The

* The ferrils are not let into the rod, that it may not be weakened.

† In screws of this shape, no pressure against the screw is necessary, as in the common form where a screw-driver is used; the key cannot slip off, and the purchase upon the screw is very great.

79. The ball of the pendulum is made of lead,* and consists of two parts screwed together upon the rod. Fig. 3 is the ball seen edgewise, and shows the section down the axis of the rod where the two parts join. Fig. 4 is the same seen flatwise. The shape of the ball when screwed together is the middle frustum of a globe; it being first *turned* in the collar lathe flatwise, and then (when screwed together,) upon an arbor passing through the hole left for the pendulum rod.† Two round pieces of brass are soldered to the back part, and tapped to receive the screws that fasten the two parts together; one of these pieces of brass is seen in fig. 3, at f.

80. The place of the ball upon the rod being found nearly, it is then to be screwed fast to the rod, and not moved to regulate the clock.‡

81. On the screwed part of the wire at the bottom of the pendulum rod, is a small cylinder of brass in two parts, the screw passing through the axis of both parts. The upper part c c, fig. 4, consists of a *torus* (or part with a round edge) and a plain cylindrical part, with the 10 digits engraved in a retrograde order thereupon; the lower part consists of the torus d d only: when the upper part is screwed to its proper height, it must then be held fast, and the lower part screwed against it, so that both parts pressing each other, sit fast on the screw without any shake. The weight of this cylinder is such that one turn thereof upon the screw alters the clock a second in a day.∥ The clock is brought to exact time by raising or falling this cylinder, which may be called the regulator.**

The

* The lead with which tea chests are lined, is cheaper and fitter for this purpose than common lead. It has a mixture of zink in it, which makes it *turn* better in the lathe.

† By this means the shape of the ball is made true, and then the axis of the rod will pass through the center of gravity of the ball.

‡ It is of the utmost consequence that the ball should be firmly connected to the rod, which can hardly be, when the ball moves upon the rod in order to regulate the clock. Nor is it easy to bring the clock to time, when the whole ball is to be shifted, for then a very small part of one turn of the regulating screw will affect the clock much, and often irregularly; owing to the inequality of the screw, or nut, or the part of the ball which bears upon it.

∥ See the method of calculating the weight of this cylinder in par. 172.

** Most pendulum balls are made with a sharp edge, that the resistance of the air to the motion of the pendulum may be as little as possible. Some degree of this resistance may perhaps be no disadvantage to a clock. The absolute quantity of resistance in different states of the air varies very little: And as the resistance increases with the arch described by the pendulum, it may serve as a check, when from other causes the pendulum has a tendency to cross out beyond its usual quantity. Mr. *Harrison*, if I mistook him not, was of opinion, that a proper degree of resistance contributed to regulate the motion of balances; if so, why not of pendulums?

If an hollow cylinder of wood, capable of receiving the end of the rod a, fig. 4. be interposed between the regulator c c and the bottom of the ball; screwing up the regulator will then raise the ball to the proper height, where it must be fixed; after which this cylinder should be removed.

The conical part b, fig. 4, at the bottom of the wire on which the regulator turns, is filed flat, down the axis behind, that its point may come near the index plate, on which is shown the number of degrees and minutes that the pendulum describes on each side of the perpendicular.

82. Having thus described the pendulum rod with its ball, I shall now describe the manner of suspending it.

It must first be premised, that the whole back of the clock-case is *framed*, having a strong broad rail at the top, to which is screwed the cock whereupon the pendulum is suspended. This rail is fastened with two screws to a transverse piece of wood reaching across the back of the case. These screws are half an inch diameter, and 3 inches long, and have square heads between which and the rail are interposed *washers* or cylinders of brass $\frac{3}{8}$ of an inch thick, and $2\frac{1}{2}$ inches diameter: These screws are tapped very tight into the transverse piece itself, being forced by a long *spanner* so as to cut their own threads quite through it.* The transverse piece is 4 inches by 3; 18 inches long, and is fastened by screwed bolts passing quite through the wall. The clock case is fastened to such another transverse piece below.†

83. Fig. 2. is the cock on which the pendulum is suspended, seen from the right side of the clock; fig. 5. is the same seen from the front. Fig. 2. plate II. is a perspective view of it. This cock consists of a plate of brass a a, to which is rivetted a part, consisting of two plates or planes of brass, b b and c c, at right angles to each other. The shapes of these planes in fig. 5. are marked with dotted lines. If one of these dotted figures could be raised up from the plane of the paper by turning it round the lines c 1, c 2, and the other by turning it round the lines c 1, b 5, till they met each other and stood perpendicular to the plane of the scheme; they would then exactly represent this part of the cock. Their thickness is shown by the shaded part of fig. 5. The plates or planes represented by the two dotted figures are both cast in one piece, having three pins as large as their thickness will admit, one in the angle (at c 1,) and one at each end (c 2. b 5.) by which the whole is rivetted‡ to the plate a; both planes being at right angles to the plate

* See par. 1.

† It has been objected that the elasticity of wood is liable to variation; perhaps it may; but if the wood is dry, and strongly compressed to the wall by the screws, there will always be elasticity enough in it to keep the clock case as firm as the wall itself. The transverse pieces must shrink greatly indeed before the screwed bolts will allow any motion in the transverse pieces, considering how much they can be compressed, and how much the iron bolts (being extended) will spring against them. The change in the elastic force of the wood is too small a part of the whole compressing force to have any sensible effect.

‡ It is put together by rivetting, that the parts when separate may be *hammer-hardened*.

plate a, as well as to each other. In fig. 2. d d is a plate of brass, screwed against the part b b, by the screws e 1, e 2, a portion of the plate d d in the shape of a parallelogram, being in contact with a part of the plane b b, of the same shape, marked b 1, b 2, b 3, b 4, in fig. 2. The pendulum spring is pinched by the screws e 1, e 2, between the plate d d and this part of the plane b b. The plate d d is seen edgewise in fig. 5. ||

84. The plate a a, fig. 2, and 5. is screwed to the broad rail at the back of the case by two strong screws f f, which are tapped both into the rail and the brass plate g; these screws have square heads, and brass *washers* under them, as may be seen in fig. 2. The holes in the plate a, through which the screws f f pass, are oblong, so that when the screws are released the plate a a may slide up and down between four pins h h h h, fig. 5. By this means the cock may be adjusted to such an height, that the center of motion of the pendulum (or place where the spring bends) may be exactly level with the *verge* or arbor of the paletts. The cock is raised by a wedge interposed between the lower edge of the plate a a, and a piece of wood screwed to the back rail; when the cock is adjusted to the proper height, and fixed by the screws f f, the wedge may be taken away. If the cock is too high or too low, a grating noise will be heard in the parts where the crutch is in contact with the screws s s, hereafter described; when all is still, it is a sign that these parts have no relative motion against each other.

85. When the pendulum is to be suspended upon the cock, take out the screw e 1, and release the screw e 2; hang the pendulum spring between the plane b 1, and plate d, fig. 2, putting the button a and the button opposite to it into notches made to fit them; return now the screw e 1, into its place, but do not tighten it; the pendulum being now supported by the two buttons, and hanging down freely, first tighten the screw a, fig. 1. and then the screws e 1, e 2, in fig. 2, and the pendulum is secured in its place. The clock is afterwards put to it.*

86. I

|| The faces of these parts that come into contact, may be filed quite flat, when the plate d is taken off; and thus the spring may be pinched flat and firm between them.

* As the pendulum hangs on a cock screwed to the back of the case, and not to the frame-plates as usual, there is no necessity to take the pendulum down, when the wheel work is to be cleaned, and consequently the rate of the going of the clock will not be altered.

It seems proper to pinch the spring quite tight, both between the parts of the rod, by the screw a, fig. 1, and between the cheeks of the cock, by the screws e 1, e 2, fig. 2. When the spring has liberty between the cheeks, and can beat against each side, its force is uncertain. If the spring is suspended by a lever above the cock, and has liberty between the cheeks, or in the slit of a cock of the common construction; part of the lateral motion of the pendulum will be communicated to that lever by the action of the spring against it. The quantity of motion communicated by such means is uncertain, and therefore the part remaining in the pendulum is likewise uncertain. The mode of suspension should be such, that none of the lateral motion of the pendulum,

as

86. I shall now show the manner of continuing the motion of the pendulum by the action of the clock. a in fig. 6. is the verge on which the paletts are fixed, b b is a round piece of brass rivetted on the collet f; c c is the stem of the crutch,† seen edgewise; in fig. 7. it is seen flatwise. In the center of the head is an hole A, which just fits the verge; E E are two circular slits in this head. In fig. 6. d d is another round plate of brass fitted loose on the verge. The screw e and another opposite thereunto go through the fixed plate b and slits E, E, and are tapped into the plate d, so that the crutch has a considerable motion round the center of the verge, and may be fixed in any position by these screws: only one of the screws can be seen in the figure. At the other end of the stem of the crutch, fig. 7. is an hole B, to receive the screwed shank of the steel piece m l n, fig. 6. & 8. This piece is at first turned round, (its section is shown in fig. 6.) and then the part n n filed flat as seen edgewise in fig. 8. its thickness being $\frac{1}{4}$ of an inch; the end of the flat part appears at n in fig. 9. The shoulder l l, being turned flat, the screwed shank m is put through the hole B, fig. 7. and the whole screwed against the crutch by the nut p, fig. 6. q is a circular brass plate interposed between the nut and crutch; this plate is turned hollow towards the crutch, and round towards the nut.* The flat face of the steel piece must be set parallel to the line A B, fig. 7.†

87. An oblong hole t t, fig. 9. is pierced through the wooden rod, in the direction of the flat of the spring. Two fine steel screws s s are tapped through

as it vibrates, can be communicated to the parts of the apparatus by which it is suspended; nor should the whole, however firm, be liable to be disturbed by foreign causes.

The great mischief of disturbing forces of any kind, in this part, is evident from Mr. *Ellicott's* experiments related in the *Philosophical Transactions*, N^o 453. Vol. XLI. for the year 1739.

† When the lower part of this piece, having two branches, clasps the pendulum rod, it is called, *the fork*, when it has only one stem that goes through a slit in the pendulum rod it is called *the crutch*.

* The use of this dish-like plate is to spring against the nut; if the stem of the crutch only were compressed by the nut, it would yield so little that the nut could not be made to draw. When the elastic force of the body compressed is so great that the screw can be made to turn only a very little way after it begins to act, the screw will then become loose and turn back again by any little blow or jar.

This screw has 50 threads in an inch.

‡ You may try if the flat stands right, by applying a straight edge to each face of it. If this edge passes equally distant on each side of the pivot of the verge, then the flat stands right, if not, it may be set right by turning this whole steel piece in the hole B. If any one suspects that the head A may turn between the cheeks after the screws are forced; let him grind these parts together with a little emery; and so much of it will stick in the brass head A and the cheeks, that nothing can stir the crutch after the screws are set up: by the same means the steel piece m l n may be secured from turning.

through the middle of the cheeks or sides of this hole. These screws pinch the flat part *n n* of the steel piece *m l n* between them. The ends of the screws which bear against the flat are rounded off; these ends and the flat part of the piece *m l n*, against which they act, must be made as hard as possible. The holes for the screws must be made exactly at right angles to the flat of the spring, and also must pass precisely through the axis of the rod. These screws are $\frac{1}{16}$ of an inch in diameter, and have 80 threads in an inch; after they are hardened and cleaned they must be carefully entered tight into the holes, and forced so as to cut their own threads in the wood; after which they must never be drawn quite out. ‡

88. When you set up the clock, having first suspended the pendulum as before, par. 85. draw back the screws *s s*, fig. 9. so as to leave room enough for the flat *n* to enter between them. Release the screws *e*, fig. 6. so as just to let the verge move stiff in the hole *A* of the crutch. The frame containing the wheel-work must then be set into its place, in doing which the flat of the crutch *n n* must be carefully directed between the screws *s s* which pass through the sides of the rod; the frame is then to be screwed to the rising-board as usual. The crutch must now be held fast, and the paletts and verge turned about a little so as to bring the clock nearly *into beat*: || the screws *e* must then be tightened so as to
set

‡ There is an absolute necessity, that the screws *s s* should be screwed into the wood itself: If these screws were tapped into an hoop of metal only, and the rod should shrink, it would leave the hoop which would then have liberty, and by this means a great part of the force of the clock would be lost.

As the screws pass through the wood across the grain, although the threads are so fine, yet they will hold with an amazing force, if they are made to cut their own way, and are turned in tight and with care.

If this construction is used in metalline rods, the screws *s s* cannot be made without some liberty in the screw-holes; but they may be kept tight from shaking, in the following manner: *a a* is a plate of brass seen edgewise in plate IV. fig. 5. and flatwise in fig. 4. The hole in the middle of this plate is tapped to fit the screw *s*, and the plate is a little bent to make it spring against the cheek or side of the pendulum rod *b*. The plate *a* being pressed flat against the cheek, the screw *s* must be entered through both the plate and cheek of the rod and then the springing of the plate *a* against the cheek will keep the screw *s* bearing outwards with one constant force, whether that screw be turned backwards or forwards. *c c* are notches at each end of the plate *a*, for receiving steady pins, to hinder the plate from turning round with the screw.

If a strong springing plate like this were applied to the micrometer screw of a quadrant; the telescope with the index would instantly obey the screw both backwards and forwards.

|| A clock is said to be *in beat* when its beats follow each other at equal intervals of time. If the wheel escapes when the pendulum is at an equal angular distance on each side the lowest point, the clock will then be in beat. If the pendulum be furnished with an index plate, then by observing at what distance on each side of the lowest point the wheel escapes, you may know more exactly whether it be in beat or not, than you can by the ear alone.

set the paletts and verge fast to the crutch.* The clock may afterwards be adjusted into beat to the utmost precision by releasing one of the screws s s, fig. 9. and screwing up the other: In setting up these screws, care must be taken not to force them against each other, which would certainly strip the threads in the wood. The rule is this, you must always hear the flat n strike against the screws s s, and if you do but hear it, they cannot be too close; you must likewise see that the verge has liberty endwise, which it cannot have unless the flat be free between the screws. These parts must never be oiled.†

89. Two *cheeks* or pieces of wood $\frac{1}{2}$ an inch broad and $\frac{3}{8}$ thick are laid across the hole in the rising-board, through which the pendulum rod passes. These cheeks are parallel to the back of the case, and about $\frac{1}{8}$ of an inch distant from each side of the pendulum rod which swings between them. Their upper face is cut into a circular arch, whose center is the center of motion of the pendulum. A wire x x, fig. 6. is put through the pendulum rod parallel to the flat of the spring, that is, at right angles to these cheeks just above their upper face. The use of these cheeks is to catch the pendulum by means of the wire x x if the spring should break, otherwise the pendulum falling on the crutch would break the pivot of the verge. These cheeks may be put into their places and screwed to the rising-board after the pendulum is suspended upon the cock.

90. This construction of the parts before described, serves to set the clock into beat without bending the crutch, which is both unmechanical, and may endanger the pivot of the verge;‡ but the principal design of it is, that the whole force of the wheels may be impressed on the ball of the pendulum: This is chiefly effected by making the flat n n and screws s s of steel, and hardening the parts which act upon each other as much as possible, || hard steel having a greater elastic force than any body we know except perhaps diamonds or rubies, which I suppose might be used here with advantage.

91. If instead of hardened steel, the pin of the crutch, which passes through the pendulum rod, be made of wood, part of the force of the clock will be spent in indenting the fibres of the wood, part only will reach

* The back frame plate must be cut, so that you may get at the heads of these screws with a key, from the front of the clock.

† Some clock makers have found a difficulty in keeping their clocks going, by reason of the oil failing in these parts. I have now a clock of the construction here described, that has gone three years without any oil at all in this place, and crosses out now nearly as much as it did at first.

‡ Another construction of the crutch for setting the clock exactly into beat is given by *M. Berthoud*, in his essay on clock-work.

|| This was suggested by Mr. *M*.

reach the pendulum ball; still more of that force will be lost, if instead of wood, any softer substance intervenes: A piece of paper interposed between the ends of the screws *s s* and flat *n n*, will much lessen the motion of the pendulum; if a piece of soft leather be interposed, the clock will hardly go at all. *

92. It contributes further to this end (of transferring the whole motion with certainty to the ball) that the crutch acts edgewise, and that the rod being $\frac{5}{8}$ diameter, is much stiffer than one of steel of the same weight. Any one will see that if the ball were suspended by a thread only, the force of the crutch would be wholly spent in bending that thread, and no motion be communicated to the ball. The case will resemble this in some degree, if the rod is weak, and unelastic: Part of the force of the clock will be spent in bending the rod backward and forward, part only impel the ball. For this reason it is a fault in the construction of a pendulum rod, to have it consist of many parts and joints, especially if the ball is likewise loose upon the rod. In some pendulums of this sort, the ball may be heard to grate upon the parts that support it as the pendulum vibrates. †

93. The crutch here described has this further advantage in its construction, that it acts upon the pendulum rod in a point very near its axis, and in a direction passing through that axis at right angles to the flat of the spring, all which can be effected with ease and certainty in this method.

* Whenever motion is communicated through bodies imperfectly elastic, some part of it will be lost, and both the part so lost and the part communicated will be uncertain, because the degree of elasticity in such bodies is always uncertain. The elasticity of wood, and of most other bodies that are imperfectly elastic, may be changed by the weather, by the beating of the parts against each other, and by many other causes. Even if the elasticity be perfect, yet if it be very weak, motion communicated through such a body may be lost many ways. The weaker the elasticity of any body is, (a spring for instance,) the more must it be compressed before it attains a given force. The circumstances of the machinery may not allow the spring to be so far bent as to acquire an elastic force equal to the compressing force, and then the spring cannot, by restoring itself, generate so great a motion as the whole compressing force immediately applied could have generated; and thus, in trying to communicate motion through such a spring, part of it may be lost. Or if we suppose the spring to be fully compressed, yet if sufficient time cannot be allowed, so that it may intirely restore itself and exert the whole of its force, it cannot then generate a motion equal to what the original force, either immediately applied, or acting through a stronger spring, would have produced; and thus part of the motion designed to be communicated through the medium of such a weak, though perfectly elastic spring may be lost. For these reasons if the crutch of the clock were made of a tender watch spring, the pendulum could hardly be kept in going, although that spring were perfectly elastic. These considerations may show that it is of some importance to make both the crutch and rod, strong and stiff.

† When the force of the clock wheels is in a great measure spent in moving the parts of a complicated pendulum rod among themselves, that portion of it which reaches the ball,

method. When the force is impressed on the pendulum rod, in a direction not passing through its axis, it will generate in the ball two motions, one vibratory, the other rotatory, round the axis of the rod; and this is the reason why in some pendulums, the ball has constantly a waving motion, as well as a vibratory one. † To prevent this, common clock makers fit the flat of the pendulum rod tight into the fork. In this case, if the flat of the spring is not precisely parallel to the flat of the rod, the spring will twist the flat of the rod against the fork, and the clock will hardly go at all. Some recommend a suspension by two springs, to prevent the pendulum from twisting: but it is hardly possible to get two springs whose strength is so exactly equal in every part, that each shall bend alike and in the same place; and if they bend in different places, or with different degrees of strength in the same place, that will occasion an irregular twisting motion.

94 In the construction here described, no force is used to prevent that twisting motion, which may be easily given to the pendulum by hand, yet it is not the least subject to it from the action of the clock only; nay, if that motion is given to the pendulum by violence, it will soon cease, notwithstanding the action of the clock still preserves the vibratory motion.

The clock whose pendulum is here described is in the possession of Mr. *Nairne*, near the Royal Exchange.

ball, will be very uncertain: for these parts from many causes, will move sometimes more, sometimes less freely. Somewhat too may depend upon the nature of the motion these parts are capable of. If they are not susceptible of lateral motion, in the direction of the vibration, (as seems to be the case of the grid-iron pendulum) the motion communicated by the clock to the ball being always in that direction may be certain and uniform.

† The same will happen if the spring be not in the middle of the pendulum rod, or if one edge of the spring be thicker or stronger than the other, or if one edge be stretched so that the pendulum bears wholly on the other. Observe the light reflected from the spring as it bends: if the termination of that light moves regularly up and down the spring and is always perpendicular to it, it is a sign that the spring bends regularly, and that it has equal strength every where right across it.

T H E
P R O P E R T I E S
O F

HADLEY'S QUADRANT DEMONSTRATED.

95. **L**ET $NI n$, and $RH r$, plate IV. fig. 3. represent the sections of the plane of the figure, by the surfaces of two speculums standing perpendicularly thereon. Let BI be a ray of light falling on a point I of the first speculum, and reflected thence to a point H of the second speculum, and by it into the line HO ; then the angle between the incident ray, and the ray after two reflections, is double the angle between the speculums.

Since the incident ray BI is in the plane of the figure, the reflected ray $I H$ will be so too;* and because the ray $I H$ is in that plane, so will also the reflected ray HO ;* the rays BI and HO therefore being both in the plane of the figure, let them (when produced) meet in E , and let the two sections $NI n$, $RH r$, (produced) meet in S , then will ISH be the inclination of the reflecting planes to each other,† but ISH is the difference of the angles IHR and HIS .‡ Produce EH backwards to A , and because by the laws of reflection $IHR = EHS = RHA$,|| therefore IHA is double of IHR . In like manner because $HIS = BIN = SIE$,|| therefore HIE is double of HIS ; but IEH is the difference between IHA , and HIE ,‡ that is between twice IHR and twice HIS , or it is double the difference of the angles IHR and HIS , that is double the angle ISH .

96. *Cor. 1.* The angle between the speculums being given; the angle BEH between the incident ray and ray after two reflections will always be the same, whatever be the angle of incidence of the ray BI , on the first speculum.

97. *Cor. 2.* If the place of one or both the speculums be changed in any manner, that neither alters their inclination to each other, nor to the plane in which the incident and reflected rays lie, then the angle between a ray incident on the first speculum I , before this change, and a ray incident upon it after such change in the place of the speculums, is equal to the angle between those rays after two reflections.

Let $BI E$ be a ray incident on I before any change is made in the
place

* *Smith's Optics*, Art. 7. † Def. 6. and prop. 19. El. 11. ‡ 32 El. 1. || 15 El. 1.

place of the speculums, and let $H E O$, be that ray after two reflections. Again let $B N F$ be a ray incident on I after the change in the places of the speculums, and $r \epsilon O$ that ray after two reflections meeting the former reflected ray in O ; then $E B F$ the angle between the incident rays is equal to $\epsilon O F$ the angle between those rays after two reflections. For let the incident ray $B N F$ produced meet the reflected rays in F and ϵ , then in the triangles $B E F$, $O \epsilon F$, we have the angle $B E F = O \epsilon F$ each being double the angle between the speculums, and $E F B = \epsilon F O$,* whence $E B F = \epsilon O F$,† or (if A and α are taken in the lines $O F H$, $O \epsilon \gamma$, produced) $= A O \alpha$.

98. *Cor. 3.* Hence if the speculums, keeping their relative situation, have a common motion upon the plane to which they are perpendicular, and the point B is so far distant that the angle $E B F$ between the rays incident on I in two different places of that speculum vanishes, then the angle $A O \alpha$ between those rays after two reflections also vanishes: Hence a distant object B , seen by two reflections, will appear to the eye placed at O , at rest, notwithstanding such a motion of the speculums.

99. *Scholium.* If the speculums, keeping their relative situation, have a common motion round the visual ray $H O$ as an axis, the incident ray $B E$ will describe a conical surface, and the point B a circle, whose plane is perpendicular to that in which the axis of motion lies. Hence objects placed in the circumference of that circle will be successively seen by the same ray $H O$. But as the direction of the ray $H O$, by which these objects are seen, is not changed; they will constantly be referred to the same fixed point A ,‡ and their appearance will be the same as if the circumference of that circle with every object in it, passed successively through the point A , turning round the line $B E$ as an axis. Hence any one of these objects as B , will by such a motion of the speculums round the visual ray $H O$, appear to cross at right angles the plane in which the rays $H O$, $B E$ lie.

100. In the construction of *Hadley's* quadrant, the first speculum, called the index-glass, turns round an axis perpendicular to the plane of the quadrant passing through a point I in $N n$, the section of that plane by the index-glass. The other speculum, called the horizon-glass, is fixed; $R r$ represents the section of the plane of the quadrant by the horizon-glass. The point I in the section $N n$, and the middle point H of the section $R r$ are called the centers of these glasses, and are the intended points of reflection. These two centers, and the place of the eye O , are assumed as is most convenient for the particular purposes for which the instrument is designed. The points O , H , and I , being thus assumed the position

* 15 El. 1.

† 32 El. 1.

‡ *Smith's Optics*, Art. 101.

sition of the horizon-glass is determined; for the rays $O H$, $H I$, must make equal angles with its surface; in practice its position is right when the eye at O sees the center of the index-glass I , by reflection from the center of the horizon-glass.

The lower half only of the horizon-glass is silvered over, the upper half is left clear, through which one of the objects A is seen directly, while the other B is seen by reflection from the lower half. The axis of the telescope passes through the line which separates the silvered and unsilvered part, and is parallel to the line $H O$ in the plane of the quadrant.

The plane in which the incident and reflected rays lie, and in which the eye is to be placed, strictly speaking, is not the plane of the quadrant, but a plane parallel thereto, passing through the axis of the telescope; the distance between these two planes is indeed so small in respect to the distance of the objects, that they are in practice considered as one. Sometimes instead of a telescope there is only a plain tube to direct the sight; the axis of this tube, or axis of the telescope when there is one, may be called the axis of vision.

101. To make an observation, the quadrant must be held in a plane passing through the two objects A and B , and the telescope or tube directed towards the object A , so that it may be seen directly through the unsilvered part of the horizon-glass. The index with the glass fixed thereupon is then to be turned about until the other object B is seen by reflection from the silvered part of the horizon-glass. If the quadrant be now turned to and fro round the axis of vision, the object B will seem to vibrate perpendicularly across the plane in which both objects lie. The index of the quadrant must then be further moved until the object B seems in this vibratory motion to pass right over the object A , so that when the two objects are brought together they may coincide or unite in one,* in the center of the field of the telescope, or in the center of the horizon-glass when a plain tube only is used.

While the index continues unmoved, the objects seen through the plain tube will remain at rest, notwithstanding any motion of the quadrant in its own plane; if the objects are seen through a telescope, they will by such a motion of the quadrant have a common motion in the field of the telescope, but will keep the same position in respect of one another, and no motion of the instrument whatever will separate the objects from each other in the direction of the plane passing through them, unless the object seen by reflection be very near.

The

* It is easier to distinguish whether the objects exactly coincide in crossing one another, than if the quadrant had been held steady in their plane, and the object B brought upon A by moving the index only.

The two objects A and B thus appearing to coincide,* the index then shows on the limb the double inclination of the reflecting planes, equal to the angle B E A, which the two objects would subtend to the naked eye at the point E. This indeed differs from the angle B O A, which they really subtend to the naked eye at O, by the angle E B O or I B O; therefore the angle I B O may be called the error of the quadrant, whose quantity varies according to the following rules, as the place of the object B seen by reflection is changed.

102. *Case 1.* When this object is at b in the line O I produced, the point E removes to e, coinciding with O, and the error is nothing. Now the sides of the triangle O H I measured upon the instrument, give the angle I O H, which the two objects make when their angular distance shown on the limb needs no correction.† If the angle between the two objects exceed this, then I E H exceeds I O H, and the error I B O must be subtracted; if the angle between the two objects be less than I O H, then this error is to be added to the angle shown on the limb.

103. *Case 2.* If this object be placed at β in a line passing through I, and parallel

* In strictness, the two objects will never appear to coincide perfectly, unless seen by rays coming from the same point of the horizon-glass, in which case the object B must be bright enough to be seen by reflection from the unsilvered part of it. This is frequently the case with respect to the heavenly bodies; thus a star may be actually seen upon the reflected image of the moon, when that image is a little darkened by a faint red glass; but this is not the case with land objects, especially distant ones; and nothing more can be done in these circumstances than to bring the object seen by reflection exactly under the other, so that by turning the quadrant round the axis of vision, they may seem to join or meet at the separation of the silvered and unsilvered parts of the glass.

I have frequently tried to distinguish more accurately the coincidence of land objects 10 or 15 miles distant, by a telescope magnifying 8 or 10 times, but without any success. The images of such faint objects in a telescope cannot be seen upon each other as those of luminous bodies may. Even in very near objects, both images cannot be thus seen at once in the telescope, but one of them will always seem bright, while the other quite disappears; and sometimes they will appear and vanish by turns with the least change in the manner of holding the instrument.

As the *Hadley's* quadrant requires no extraordinary steadiness, it would be a great convenience could it be employed in extensive land surveys, such as those of a county, or in tracing a meridian line, &c. but the objects whose angular distances must be taken in such cases, are generally so small and remote as to require a telescope magnifying at least 8 or 10 times to make them fairly visible; and in such a telescope the images of both objects can never be seen together, as has been said; otherwise the mirrors can be ground true enough to make the reflected image sufficiently distinct. A Theodolite of the old form, with two telescopes, one for each object, is I believe the best instrument that can be used for such purposes. With a good instrument of this sort of 9 inches radius, angles between distant objects may be taken very well to a single minute, with an *Hadley's* quadrant and a plain tube, hardly nearer than 5 or 6 minutes, unless in very favourable circumstances.

† The instrument is usually so constructed that this angle is 45° , or near it.

parallel to $A O$, then the angle $I \beta O = A O \beta$, or the angle which the two objects subtend to the naked eye. The point E in this case recedes *in infinitum*, the glasses are parallel, and the angle shown on the limb is nothing.

104. *Case 3.* If this object is placed at bb in the line $O H$ produced, then the point E removes to ee , coinciding with bb , and the angle of error $I bb O$ is the same with $I ee H$, or the angle shown on the limb, which is evident because the two objects A , bb , and the eye O being in the same right line, the angle between them (seen at O) is nothing. Hence, if the image of the object bb , seen by reflection, be made to coincide with the object itself seen directly, the angle shown on the limb gives the error of the instrument in this case.

105. *Case 4.* The error of the instrument, when the object seen by reflection is in the line $O H A$, being thus found experimentally, we may thence derive the error in any other case. For let the object be placed any where else, as at B , then $B O : I O :: \text{fine } B I O, \text{ (or fine } E I O) : \text{fine } I B O$; whence if the distance $B O$ is given, the sine of the error $I B O$ is as the sine of $E I O$, or the difference between the angle $I O H$, where the error is nothing, and the angle $I E H$, shown on the limb: But when the object is at bb as before, the angle $E I O$ becomes $bb I O$, and its sine the sine of $b I bb$, or the sine of $I O H + I bb O$, the former of which is determined from the sides of the triangle $O I H$, as before, the latter is the error found by experiment on the object bb ; say then as the sine of the sum of these two angles is to the sine of the latter, so is the sine of the difference between the angle $I O H$ and that shown on the limb, to the sine of the error, to be added or subtracted according to the rule in the first case. This is on supposition that the distances of the two objects bb , and B , are equal; if they be unequal the error thus found must be increased or diminished in the inverse ratio of those distances.

106. Hence if the distance of the object B seen by reflection be always the same; the error will be greatest when the angle shown on the limb is 90° distant from the angle at which there is no error.

107. Universally, the angle $I B O$ may be had from the sides of the triangle $I B O$; whence it is evident, that if the variable sides $B I$, $B O$, are great in respect of the fixed side $I O$, this error may be neglected; in astronomical observations it certainly may. In land surveys, if we put $I O = 3,05$ inches, and the angle $B O I = 45^\circ$, the distance $B O$ must be less than 710 feet, to make an error of one minute.

108. Lastly, we have supposed that the object A , seen by the eye at O , through the middle of the horizon glass, lies in the line $O H$ produced,
but

but in fact, that object lies in another line ah , parallel to AH , whose perpendicular distance from it may be determined from the thickness, refracting power of the glass, and angle of incidence given. There will therefore be another very small error from the refraction of the horizon-glass to be added to the angle before found, the true angle to the naked eye being aOB , which exceeds AOB the angle before determined, If the angle of incidence be $22\frac{1}{2}$ degrees, and the thickness of the glass $0,15$ of an inch (both which are more than usual) the perpendicular distance between the lines AH and ah is but $0,0736$ of an inch, which at any moderate distance of the object A subtends so very small an angle, that this last error may be wholly neglected.

T H E
CONSTRUCTION AND MAGNIFYING POWER
O F
TELESCOPES MADE WITH SEVERAL EYE-GLASSES.

109. **I**N plate VI. fig. 1. let A be the first eye-glass, B the second, C the third, D the fourth, E the fifth, &c. and O the object-glass, and let O A the axis of the telescope, be the common axis of all the lenses. Let l m w be an oblique pencil passing through the object-glass, and falling on the extreme edge of the lens E which is next to the object-glass. Let O w the axis of the pencil, (represented by a black line) be refracted successively into the lines w v, v t, t s, s r, r α , cutting the axis of the telescope (when they are produced) in the points ϵ , δ , γ , β , α , respectively. Let o be the focus of this oblique pencil after refraction at the object-glass; let e, d, c, b, be the successive focuses of this pencil after refraction at each of the eye-glasses: From each of these focuses draw perpendiculars to the axis of the telescope, and these perpendiculars, o x, e g, d h, c z, b y, will be places and magnitudes of the successive images, either *real* or *imaginary*; *real* when the image is actually formed, so that it would be visible if the rays were received upon a white paper; *imaginary*, when the rays after refraction proceed as if they came from or tended to such an image, although this image is not actually formed. When the image is real, the rays of each pencil actually come to a focus; when it is imaginary, these rays after refraction diverge from, or converge towards such a focus, but are never actually united.

110. Although each lens has its proper image either real or imaginary, yet there are only two real ones in the construction here delineated, the first e g inverted, the second b y upright. It may be observed that when the number of real images is even, the object will be seen upright, when that number is odd the object appears inverted. *Galileo's* telescope, in which there is no real image, shows the object upright. This telescope cannot be applied to instruments in which cross wires are necessary, because the wires cannot be so placed as to be seen distinctly together with the object.

111. All that is essential to the construction of telescopes is only that the rays of the same pencil, which enter parallel, should likewise emerge parallel, for the object in that case will be seen distinctly; therefore the intervals and focal lengths of all the lenses except one, may be assumed

sumed at pleasure ; from whence that one must be determined. Thus if every thing be determined, except the place of one lens, for instance C ; to find the place of this lens suppose parallel rays to fall on the object-glass O, and to be refracted by it and by the lenses E and D ; then from the assumed intervals and focal lengths of these lenses, we shall get the places of the successive images ox , eg , dh , or the distances Ox , Eg , Dh . In like manner, suppose parallel rays to fall on the eye-glass A, and to be refracted by it and by the lens B, from the assumed intervals and focal lengths of these lenses we shall get the places of the successive images by , cz , or the distances Ay , Bz . From Dh , Bz , and the interval DB , we have the whole interval hz . Nothing now is wanting but to find the place of C such, that rays diverging from d , may (after refraction at C,) converge to c , or that if h be the focus of the incident, z may be the focus of the refracted rays.* This will require the solution of a quadratic equation, and care must be taken to assume the focal length of the lens C within such limits as may make that equation possible. If the place of the lens C be given, but its focal length sought, the equation will be a simple one, and always possible.

112. It has been said before, (and it follows from an Algebraic theorem given by the writers on optics †) that in constructing a telescope, the number, place, and focal lengths of all the lenses, except one, may be assumed at pleasure. This indeed is true, if nothing else be attended to, besides the course of a few rays coming from a single point in the axis of the telescope, and it be only required that the middle of the object should be seen distinctly ; but the case is very different if it be desired that all the parts of the object should appear, as far as may be, equally distinct ; for then the aberration of the extreme pencils in passing through the eye-glasses must be taken into consideration ; and the number, place, and focal lengths of the eye-glasses must be such, as may lessen at least, if not remove these aberrations. It is impossible to compare accurately the merit of the several different combinations of eye-glasses which have been proposed for this end, without entering too particularly into the theory of aberrations. Thus much may be observed in general, that in any single lens the greater the focal length, and the less the aperture, the less will be the aberration of the refracted rays, whether arising from the unavoidable defect in the figure of the lens, or from the unequal refrangibility of the rays of light. That construction of a telescope is therefore (*cæteris paribus*) the best in which the eye-glasses have large focal distances and small apertures, those especially that are concerned in forming the last image : As to the
single

* See an example of computing this in par. 130.

† *Smith*, Art. 276.

single lens by which the last image is viewed, it may be allowed to have a short focal length, especially if its aperture can be proportionably contracted: For though this lens magnifies the faults already made in the last image by the other glasses, yet it does not create new ones; and we find by experience that very deep lenses may be used singly as microscopes, without either making the object indistinct or tainting it with colour.

113. Among the various sorts of telescopes made with convex-lenses, designed to show the object upright, those with four or five eye-glasses are preferable to any made with fewer. The fewer lenses there are in the eye tube the greater must be the refraction of the extreme pencils at each lens, supposing the sum of all the refractions, or the whole change in the direction of these pencils to be the same. Now though the number of refractions is increased, yet if the quantity of each refraction be proportionably diminished; the sum of all the aberrations in these pencils will be greatly lessened,* and the loss of light, by passing through more glasses, will be very inconsiderable. Agreeably to this principle we find that an object seen through two double convex lenses, both of a size, and put close together, appears distincter near the edges of those lenses than if seen through one lens only whose focal length is equal to that of the other two so combined together. Likewise two equal plano-convex lenses show an object distincter at their edges, when combined with their convex sides touching each other, than contrariwise, especially when such lenses are applied to a telescope. Thus then the aberrations arising from the figure of the eye-glasses may be lessened by increasing the number, and diminishing the quantity of the several refractions. The principle upon which the aberrations of the other kind may be corrected in the extreme pencils is this, that the coloured rays into which an heterogeneous ray is separated at one refraction, may be again united, or more strictly, made to proceed parallel to themselves by another equal and contrary refraction. We have an example of the application of this principle in the telescope composed of three equal convex eye-glasses, where the equal and contrary refractions in the rays of those pencils which pass near the edges of the eye-glasses, so far correct each other, that in these telescopes, objects seen at the outsides of the field are intirely free from colour.†

A

* See Philosophical Transactions for the year 1753. Vol. 48. page 104.

† That is from any visible tint which is generally occasioned by the eye-glasses only; and it is these glasses only which cause that strong *iris* so commonly seen in telescopes round the borders of the field. For the colours of the incident rays are not so much separated by the object-glass as to be all of them visible at the edges of every object, as in a prism. The extreme colours indeed may be discerned when there is a strong contrast

A telescope may be constructed with three convex lenses only, (an object-glass and two eye-glasses) which shall show the object upright, but the reversing of the first image must, in this case, be wholly done by the refraction of one lens only, namely the middle lens, or second eye-glass. In this sort of telescope, the errors from the different refrangibility of light cannot be balanced by contrary refractions at the lenses which intervene between the two images, for there is but one such lens, so that the second image, which is seen through the eye-glass, must be a bad one. In fact, objects seen through such a telescope appear so very indistinct and coloured, that though its construction is the simplest of all others (composed of convex lenses, and showing the object upright) yet it is never used in practice: However, the rule for combining the glasses, and finding the magnifying power in telescopes of this kind, may be found in *Smith's Optics*, Art. 275.

114. In the construction here delineated, the lens E, which intercepts the rays before the first image is formed, diminishes indeed the magnifying power, but improves the distinctness of the telescope, by lessening the diameter of the apertures of the deep lenses D and C. The extreme pencil O w, which diverges from O, being refracted by this lens E into w v, is made to converge towards the axis of the telescope, so that if produced it would meet in e. By this means the semi-diameter of the lens D is reduced to D v, whereas if the first real image had been formed at o x by the object-glass only, (the extreme pencil O o in that case continuing to diverge) the semi-diameter D v must have been greater than the image o x, to take in the same field.

The rays belonging to this (and every other) pencil which diverge from e g, the first real image, must be made to converge again by the two lenses D and C, that a second real image may be formed upright. Two lenses are employed for this purpose, because the errors in the second image will be lessened by their contrary refractions. Supposing therefore their convexities equal, and that the rays of this pencil (refracted into v t) go parallel between the lenses D and C, or nearly so, then it is evident that the focal length of D must be equal to the distance e v ($= g D$) or nearly

ly
traft of light and shade; but the effect of this dispersion at the object-glass appears mostly by its making the picture seen in the telescope all over confused, its parts ill defined, and their terminations not *sharp*. Whatever faults are occasioned by the object-glass in this picture, they will be the same in every part of it; whereas those occasioned by the eye-glasses, will be different according to the part of the field in which the picture is seen. The indistinctness of the first picture formed by the object-glass cannot be remedied by the eye-glasses, but the colours which these glasses would occasion may be prevented by proportioning and combining them properly.

ly so; therefore the lenses D and C, having a short focal length, would by no means admit of an aperture whose semi-diameter is greater than ox . It may be further observed, that this pencil, which at first diverged from the axis of the telescope in the angle $w O E$, after refraction by the lenses E and D, converges to that axis in the angle $v \delta D$, therefore the whole change now made in the direction of this pencil is the sum of these two angles $w O E$ and $v \delta D$. By the interposition of the lens E, this change is made at two refractions (at w and v) which must otherwise have been made by the refraction of the lens D only.

115. In like manner, the other lens B, which intercepts the rays just before the second real image is formed, diminishes indeed the magnifying power, but makes the telescope more distinct. The extreme pencil we have been considering, after refraction at t by the lens C, diverges from the axis of the telescope, proceeding as if it came from the point γ , but being refracted by the lens B into $s r$, is made to converge, so that if produced it would meet the axis of the telescope in β . This lessens the last image, reducing it from $c z$ to $b y$, and as it is this image which is viewed by the eye through the eye-glass A, the interposition of the lens B lessens the magnifying power, the eye-glass A remaining the same. The extreme pencil $s v$ thus converging upon the eye-glass A, the semi-diameter of this glass will be reduced to $A r$, whereas had the lens B not been interposed (the extreme pencil $t s c$ continuing to diverge from γ) the semi-diameter of this eye-glass must have been greater than the image $c z$, to take in the whole field. As a small aperture of the eye-glass A is sufficient to take in the whole field when the pencils thus fall upon it converging, this lens may be allowed to have a shorter focal length, and thus compensate for the loss of magnifying power by the interposition of the lens B without increasing the aberration of the extreme pencils.

The truth of this may be shown experimentally in any telescope of this or the like construction. Take out the second eye-glass and draw out the eye-tube to make the telescope distinct again, and you will find the magnifying power increased, the field diminished, and perhaps indistinct near the edges.

In the double microscope, a broad lens of a long focus is commonly interposed between the object-glass and image formed by it. The astronomical telescope is likewise frequently made with two eye-glasses, one of which is placed between the object-glass and image; both these constructions proceed upon the same principle, and are designed to make the instrument distincter with the same field and magnifying power, or with a
given

given magnifying power to enlarge the field and yet preserve the edges of it distinct.*

When the several pencils fall on the eye-glass A, converging as before, that glass is usually made plano-convex, and the plane side is turned towards the eye, the extreme pencils, in that case, both falling upon and emerging from this lens more perpendicularly than if it were a double convex. When these pencils converge very much, as in reflecting telescopes, a meniscus eye-glass is used for the same reason.

116. If the object were seen by the naked eye at O the center of the object-glass, it would appear under an angle equal to $\angle O O x$; but when it is seen through the telescope, by the eye at α , it appears under the angle $\angle r \alpha A$. The proportion of these angles gives the magnifying power of the telescope; the former being to the latter as unity to a number, which is called the magnifying power.

117. From o, the extremity of the first image, draw a line o E through the center of the lens E, and it will terminate the second image e g. For as the object and first image, subtend equal angles at the center of the object-glass which forms that image, so the first image o x, (considered now as an object,) and the second image e g will subtend equal angles at the center of the lens E, which forms the second image; because the line E o, considered as a ray belonging to the focus o, and incident upon the lens E, suffers no change by the refraction.† In like manner the line D e d, drawn through the extremity e of the second image, and the center of the lens D, will

* A rule for finding the focal lengths of two eye-glasses, which may be substituted instead of a single one, without altering the magnifying power or field, is given in Art. 638 of the remarks at the end of *Smith's Optics*, and is the rule generally followed by workmen. It is this: The focal length of the first of these eye-glasses (that which is next the eye) must be $\frac{2}{3}$ of the given focal length of the single eye-glass, and its aperture $\frac{1}{3}$ of the aperture of that glass; the focal length of the second of these eye-glasses must be double that of the single eye-glass, and its aperture equal to that of the single eye-glass. The interval between these two eye-glasses must be $1\frac{1}{3}$ of the given focal length of the single eye-glass, and that which is next to the object-glass, must be placed nearer to it than the single eye-glass must have been placed, by double the focal length of the single eye-glass. Both these eye-glasses are to be plano-convex, having their plane sides turned towards the eye, whose distance from the first of them must be $\frac{1}{3}$ of the focal length of the single eye-glass. It may be observed, that the focal length of the eye-glass next to the eye is less than that of the single eye-glass in the ratio of 3 to 2; but then its aperture is diminished in the ratio of 3 to 1; the aperture of the other eye-glass is equal to (or indeed it may be rather less) than that of the single eye-glass, and its focal length is doubled, so that the telescope will undoubtedly be distincter near the edges of the field with two such eye-glasses than with a single one.

Another combination of two eye-glasses for the same purpose may be found in *Huygen's Dioptrics*, prop. LI.

† *Smith's Optics*, Art. 229. & 245.

will terminate the third image dh , formed by that lens D . Again, from d , through C , draw dCc , and it will terminate the image cz , formed by the lens C . From c , through B , draw cbB , and it will terminate the image by , formed by the lens B . Lastly, from b draw bA , through the center of the lens A , it will terminate the image formed by that lens at an infinite distance; or more properly the rays diverging from b , will after refraction at A , all proceed parallel to bA .

Now the angle oOx will be to the angle $r \propto A$, or to its equal bAy , in a ratio compounded of

	oOx	to	oEx
of	oEx ,	or its equal	eEg
		to	eDg
of	eDg ,	or its equal	dDh
		to	dCh
of	dCh ,	or its equal	cCz
		to	cBz
and of	cBz ,	or its equal	bBy
		to	bAy

But	oOx	is to	oEx	as	Ex	to	Ox
	eEg	is to	eDg	as	Dg	to	Eg
	dDh	is to	dCh	as	Ch	to	Dh
	cCz	is to	cBz	as	Bz	to	Cz
	bBy	is to	bAy	as	Ay	to	By

Or, taking the several terms of these last ratio's alternately, we have the whole in a ratio compounded of Ex to Eg , Dg to Dh , Ch to Cz , Bz to By , and lastly, of Ay to Ox . That is in a ratio compounded of the several ratio's of the distance of the focus of the incident rays at each lens to that of the emergent rays, and of the focal length of the eye-glass to that of the object-glass.

118. Otherwise thus; if the telescope consisted of an object-glass, and an eye-glass only, (the first image ox only being seen through A) the ratio which gives the magnifying power would be that of the focal length of the eye-glass, to the focal length of the object-glass.* But if the last image by , seen through A , be made greater or less than the first image ox by the interposition of more eye-glasses, the magnifying power will be increased or diminished in the same proportion. It will therefore be in a ratio compounded of the focal length of the eye-glass to that of the object-glass, and of the linear magnitude of the first image ox to that of the last image by . But these images are in a ratio compounded

of	ox	to	eg	or of	Ex	to	Eg	} as before.
of	eg	to	dh	or of	Dg	to	Dh	
of	dh	to	cz	or of	Ch	to	Cz	
of	cz	to	by	or of	By	to	Bz	

* *Smith's Optics*, Article 120.

119. The case will be exactly the same in reflections from spherical surfaces, as in refractions through lenses: for in reflections the object and image subtend equal angles at the vertex of the speculum, (where the axis of the telescope intersects the speculum) just as in refractions they do at the center of the lens.†

120. If the rays of the same pencil go parallel between any of the glasses, as between D and C, then the lines D e d, c C d, drawn through the centers of these lenses to the common image d h, (removed to an infinite distance) will be parallel, the angles at D and C will be equal, the image e g will be to the image c z, as D g to C z, and the terms D h, C h, being in a ratio of equality, may in compounding the several ratios be left out. Telescopes of this kind may likewise be considered as a combination of two other telescopes, and their powers computed accordingly.

121. *Cor. 1.* Hence if the same system of eye-glasses be applied to different object-glasses, the magnifying power will be directly as the focal lengths of those object-glasses.

122. *Cor. 2.* The breadth of the whole pencil of rays l m, which falls upon the object-glass, will be to its breadth when it emerges from the last lens at r, as the magnifying power to unity.

For its breadth at O is to its breadth at w, when it falls upon E, as o O to o w, or

		as O x	to E x
in like manner the breadth at w	to that at v	as E g	to D g
	at v to that at t	as D h	to C h
	at t to that at s	as C z	to B z
	at s to that at r	as B y	to A y

which ratio's compounded together, make that of the magnifying power to unity; as appeared before.

123. *Scholium.* In the demonstration given in par. 117. the image o x is considered as the common subtense of the angles o O x and o E x, the image e g as the subtense of e E g and e D g, and so of the rest, each image being the subtense of two angles, one at the center of the lens which forms the image, the other at the center of the next lens: Instead of this, the magnifying power might be computed by considering the lenses themselves, as the common subtenses of the angles made by the axes of the oblique pencils with the axis of the telescope, at their incidence upon and emer-

† In fig. 3. let C be a speculum whose center is e, and vertex C; let o x be an object, c z its image terminated by the line o e c, drawn from o the extremity of the object through e the center of the speculum, then will o C x, and O c z, the angles which the object and image subtend at the vertex of the speculum be equal; for the former is the angle of incidence of the ray o C, the latter the angle of reflection.

Hence o x : c z :: C x : C x, as in images formed by lenses.

emergence from each lens: Thus Ew is the common subtense of the angles wOe and $w\epsilon E$. Hence the proportions of these angles at each successive refraction, and consequently the proportion of the first wOe to the last $r\alpha A$ may be obtained. Upon this principle the general theorem in *Smith's Optics*, art. 247. is demonstrated; but the former method seems more convenient as well as more natural.

124. It will not be difficult to compute algebraically the several distances of the focus of the incident and emergent rays at each lens, whence a general theorem for the magnifying power may be obtained. But theorems so very general must of course contain such complicated expressions, that it is frequently more trouble to reduce them to the common and simpler cases, than to derive theorems for every one of those cases from the first principles.

125. The course of the axis of the extreme pencil of rays, and the place of the first image being given, to find the places and magnitudes of the several images formed by each lens.

Let Ow , wv , vt , ts , sr , be the given course of the axis of this pencil, into which it is refracted by the several lenses, and let x be the place of the first image; on x erect xo , perpendicular to the axis of the telescope, meeting Ow (produced if need be) in o , and ox is the place and magnitude of the first image. From o the extremity of the first image, draw oe through the center of the second lens, cutting wv in e , and the extreme pencil which before converged to o , will, after refraction at this lens converge to e , and eg , let fall from e perpendicular to the axis, will determine the place and magnitude of the second image, and so of the rest.

The places of the several images being given, to find their magnitude and the course of the axis of the extreme pencil of rays.

Let x , g , h , z , y , be the given places of the several images formed by each lens successively; from each of these points erect perpendiculars to the axis of the telescope. From O , the center of the object-glass, draw Owo through the extreme edge of the lens next the object-glass, meeting the first perpendicular in o , and Ow is the course of the axis of this pencil between the first and second lens, and ox is the magnitude of the first image. From o draw oe through the center of the second lens, cutting the second perpendicular in e , through e draw $w\epsilon v$, and it will be the course of the axis of the extreme pencil, between the second and third lens, and eg is the magnitude of the second image, and so of the rest. The course of the axis of the extreme pencil at its emergence from the last lens A is parallel to bA .

By means of these problems, the figures designed to represent the progress

gress of the rays in optical instruments may be always delineated truly, so that the refracting power of the several lenses, as shown in the figure by the diverging or converging of the axes of the different pencils to the axis of the telescope, may be consistent with their refracting power as shown in the figure by the diverging or converging of the different rays of the same pencil to a focus among themselves.

126. The points $\epsilon, \delta, \gamma, \beta, \alpha$, in which the axes of the several pencils of rays (if produced) would cut the axis of the telescope, after refraction at each lens, may be found by computing the focuses of rays diverging from the object-glass, and successively refracted by the rest of the lenses: And the points x, g, h, z, y , or places of the several images in the axis of the telescope may be found by computing the focuses of rays falling parallel upon the object-glass, and successively refracted by all the lenses except the last.

127. Fig. 1. is taken from a telescope made by Mr. *Dollond*. The distances of the eye-glasses from each other, and from the several images are half their real distances, the apertures in the figure are the size of their real apertures; the place of the object-glass could not be represented conformably to its place in Mr. *Dollond's* telescope; but to have a perfect idea of the whole instrument, the dimensions of each part are here subjoined, in inches and decimal parts.

	Inches.		Inches.
Focal distance of A	= 1,6	Interval between A & B	= 2,6
B	= 2,6	B & C	= 3,2
C	= 3,2	C & D	= 2,95
D	= 3,2	D & E	= 3,9
E	= 6,8	E & O	= 64,25
O	= 66,6		

From these dimensions, the places of the several images, and of the points in which the axes of the pencils (produced) cut the axis of the telescope are computed as follows :

Inches.	Inches.	Inches.	Inches.
E x = 2,35	E g = 1,75	E O = 64,25	E ϵ = 7,604
D g = 2,15	D h = 6,55	D ϵ = 3,704	D δ = 1,716
C h = 9,50	C z = 4,825	C δ = 1,24	C γ = 2,02
B z = 1,625	B y = 1,000	B γ = 5,22	B β = 5,18
A y = 1,600	O x = 66,6	A β = 2,58	A α = 0,99

Hence the telescope magnifies 29,264, or in round numbers 30 times. The aperture l m is 2,25 inches, whence the diameter of the emergent pencil is 0,075 of an inch. The diameter of the first image o x is to the diameter of the last b y, as 66,6 to 1,6 $\times$ 30, or 66,6 to 48, that is as 1,3875 to 1. Therefore when the sun's apparent diameter subtends an angle

angle of $32' 6''$, its last image in this telescope will be 0,4482 of an inch in diameter.

The diameter of the aperture of the lens E, which limits the field, is one inch and $\frac{2}{10}$, whence the greatest angle of vision is $1^\circ 4'$.

128. For another example, I shall give the drawing and dimensions of a reflecting telescope made by Mr. *Short*, constructed partly with mirrors and partly with lenses, and then compute its magnifying power. In fig. 2. every part is drawn of the exact size, and placed just as it is in the telescope. In fig. 3. the speculums and lenses are placed at their real distances from each other, but their apertures are vastly enlarged, to show better the progress of the pencils of rays.

In these figures E A β is the axis of the telescope. A is the first eye-glass, B the second, C the little speculum whose center is e, and principal focus f. O is the great speculum whose center is E, and principal focus x. E o w represents the axis of an oblique pencil of rays* falling on the great speculum, and by it reflected back again in the same line to the little speculum in t, and from thence reflected into the line t s, and refracted by the lenses B and A into the lines s r, and r α , which lines t s, s r, r α , (produced) cut the axis of the telescope in the points γ , β , α , respectively. The perpendiculars o x, c z, b y let fall from o, c, & b, (the successive focuses of this pencil) to the axis of the telescope, represent the places and magnitudes of the several images. The line o e c drawn through e, terminates the images o x & c z: the line B b c drawn through B, terminates the images c z & b y, the line b A, drawn through A, determines the direction of the axis of this pencil after its last refraction.

129. To compute the magnifying power of this telescope we should measure the several focal lengths, and intervals between the speculums and lenses. Now as the distance C x is only a fourth or a fifth part of C z, a very small error in measuring the interval between the speculums will make a very great one in computing from thence the place and magnitude of the image c z, and consequently in determining the magnifying power. It will be best therefore to find this interval, (or rather the distance C x) by com-

* The writers on optics do not expressly define the term *axis of a pencil of rays* in reflections, but the ray which passes through the center of the sphere of which the speculum is formed, is usually considered as the axis of the pencil of rays because its course is not changed by the reflection, and whenever the other rays of the pencil come to a focus it must be in this line.

In the pencil here delineated, none of the rays which come immediately from the object to the great speculum, (except the axis of that pencil E w) are expressed in the figure in order to avoid confusion. Some of these rays, (and perhaps the axis itself) may be intercepted by the lesser speculum, but the rest will belong to the same focus o, as the whole would have done if no part had been stoppt. See *Smith's Optics*, Art. 281.

computation from the other measures given; for if all the focal distances and intervals except one be given, that one may be computed from the rest, as was explained in par. 111, and thus the magnifying power will be had very nearly.

130. We have therefore in this telescope (by measurement) the focal distance of A, or $Ay = 0,75$ inches: The focal distance of B $= 1,65$, that of C $= 1,23$, that of O, or $Ox = 4,30$; moreover the interval between A and B $= 1,25$ inches, between B and O $= 0,5$, from whence we are first to compute Cx.

Put b and c for the focal distances of the lens B and speculum C, and first of all $By = AB - Ay = 0,5$, but $By + b : b :: By : Bz$. * That is $0,5 + 1,65 : 1,65 :: 0,5 : 0,71739 = Bz$. Again $zx = Bz + BO + Ox = 0,71739 + 0,5 + 4,30 = 5,51739$. Call now Cx the distance sought x , and the distance $Cz = Cx + xz = x + 5,51739$; but $Cz - c : c :: Cz : Cx$. That is $x + 4,28739 : 1,23 :: x + 5,51739 : x$. Whence $xx + 3,05739 \times x = 6,7864$, and $x = 1,4918 = Cx$ sought; and consequently $Cz = Cx + zx = 7,0092$.

Now we shall find the magnifying power by compounding the following ratio's:

Cx to Cz or 1,4918	to 7,0092	} all which compounded together make the ratio of 1 to 18,775.
Bz to By 0,71739	to 0,5	
Ay to Ox 0,75	to 4,30	

It appears that interposing the lens B diminishes the magnifying power in the ratio of 0,71739 to 0,5, or 7 to 5 nearly.

By experiment this telescope was found to magnify $18\frac{1}{2}$ times.

* For determining the ratio of the distance of the focus of incident rays, to the distance of the focus of reflected or refracted rays from any speculum or lens, one rule will serve all cases, viz.

As the interval between the focus of incident rays and the focus of parallel rays coming the same way in { reflections } is to the distance of the focus of parallel rays from the speculum or lens :: so is the distance of the focus of incident rays therefrom; to the distance of the focus of reflected or refracted rays.

The first term will sometimes be the sum, and sometimes the difference between the distance of the focus of incident rays from the speculum or lens, and the distance of the focus of parallel rays; this settled, there is no ambiguity in the rule; there wants no particular direction for placing the focus of the reflected or refracted rays; the circumstances will always show whether those rays diverge or converge, and consequently which way their focus is to be placed.

P R O B L E M S
 FOR RECTIFYING THE POSITION
 OF THE
 TRANSIT TELESCOPE
 BY
 ASTRONOMICAL OBSERVATIONS.

PROBLEM I.

131. **I**N the projection of the sphere on the plane of the horizon, plate VII. fig. 1, 2, & 5. let M E P m e be the meridian, cutting the horizon in M and m, the equator in E and e, the pole in P. Let A S Z a s z be a great circle cutting the meridian in Z and z, the horizon in A and a, the equator in S and s, and a parallel of declination in R and r, and let P R and P r be hour circles passing through R and r.

Given the arches P Z, P R, and angle P Z R, to find the hour angle Z P R, or z P r.

Draw the hour circle P S, and with the pole S describe a great circle P V, which will cut at right angles both the hour circle P S in P, and the great circle A S Z a in V; then is Z P S the complement of Z P V; R P S the complement of R P V; Z E the complement of P Z; E Z S either equal to or the supplement of P Z R;

In the right angled triangle E Z S, we have $rad. : \text{fine } Z E :: \tan. E Z S : \tan. E S$, the measure of the hour angle E P S or Z P S. Again, in the right angled triangles V P Z, V P R, having the same perpendicular P V, we have $\tan. P R : \tan. P Z :: \text{cosine } V P Z : \text{cosine } V P R$, or $\tan. P R : \tan. P Z : \left. \begin{array}{l} \text{cotan. } P Z : \text{cotan. } P R : \end{array} \right\} :: \text{fine } Z P S : \text{fine } R P S$. But Z P S was found by the former analogy, and the sum or difference of R P S and Z P S gives Z P R, the hour angle sought.

132. *Cor.* If the circle A S Z a cuts two parallels of declination, one in R as before, and another in T, we have $\text{cotan. } P R : \text{cotan. } P T :: \text{fine } R P S : \text{fine } T P S$; that is, the tangents of declination are as the fines of the respective angles R P S, T P S.

133. *Scholium.* If P R be less than P V the problem is impossible; on the other hand, draw the hour circle P a, and if the polar distance is greater

greater than P V; yet less than P a, the great circle A Z a, will cut the parallel of declination twice above the horizon.

134. To apply this; Let the intersection Z fall in the zenith, (fig. 1, 2, 3.) then is A S Z a, an azimuth circle, and the problem will be, From the latitude, declination and azimuth given, to find the hour; and the rule is $rad. : \text{fine latitude} :: \tan. azimuth : \tan. Z P S = E P S$ the hour angle when the sun or star is the equator. Again, $\tan. latitude : \tan. declination :: \text{fine } Z P S : \text{fine } R P S$, which subtracted from Z P S, when the declination is north, and added to Z P S when the declination is south, gives the hour angle sought.

135. *Example 1st.* Suppose the axis of the transit telescope to be level, but let the telescope describe an azimuth circle one degree to the west of the meridian, instead of the meridian itself; what error will this occasion in transits of the sun, when in the equator, and at each tropic?

Here putting the latitude = $52^{\circ} 13'$, and the sun's declination at the tropics = $23^{\circ} 28' 20''$, we have $rad. : \text{fine } 52^{\circ} 13' :: \tan. 1^{\circ} : \tan. 47' 25'' = Z P S$. Again, $\tan. 52^{\circ} 13' : \tan. 23^{\circ} 28' 20'' :: \text{fine } 47' 25'' : \text{fine } 15' 58'' = R P S$. These arches of the equator turned into time give $Z P S = 3' 9'' 40'''$, and $R P S = 1' 3'' 52'''$; and the error sought is $2' 5'' 48'''$ at the summer solstice, $3' 9'' 40'''$ at the equinoxes, $4' 13'' 32'''$ at the winter solstice.

136. *Example 2d.* All things as before, let it be required to find when the pole star passes the telescope, supposing the declination of that star to be $88^{\circ} 3' 30''$.

The angle Z P S was before found to be $47' 25''$ therefore $\tan. 52^{\circ} 13' : \tan. 88^{\circ} 3' 30'' :: \text{fine } 47' 25'' : \text{fine } 18^{\circ} 23' 10'' = R P S$. But these angles turned into mean solar time,* give $Z P S = 3' 9''$, and $R P S = 1^h 13' 19''$, whence the pole star passes the telescope $1^h 10' 10''$ before it comes on the true meridian at the upper transit, and $1^h 16' 28''$ after it has passed the true meridian at the lower transit.

The angle R P S, in this example, might be derived from R P S in the former example, by the corollary, par. 132. thus $\tan. 23^{\circ} 28' 20'' : \tan. 88^{\circ} 3' 30'' :: \text{fine } 15' 58'' : \text{fine } 18^{\circ} 23' 10''$, as before.

137. Let now the intersections Z and z fall in the horizon, (fig. 4.) and Z E will be the complement of the latitude; and the rule is $rad. : \text{cosine latitude} :: \tan. E Z S : \tan. Z P S = E P S$ the hour angle when the star is in the equator. Again, $\cotan. latitude : \tan. dec. :: \text{fine } Z P S : \text{fine } R P S$.

The

* Allowing $23^h 56' 4''$ for 360° . See a table for this purpose, page 93, of the *Connoissance des mouvemens Célestes*.

The angle RPS added to ZPS , if the declination be north, and subtracted therefrom if the declination be south, gives the hour angle sought.

Example. Let the axis of the transit telescope be due east and west, but let the west end dip one degree below the level, what error will this occasion in the time of the transit of the sun, when in the equator, and at each tropic?

Rad. : *cosine* $52^\circ 13'$:: *tan.* 1° : *tan.* $36' 46'' = ZPS$, Again, *cotan.* $52^\circ 13'$: *tan.* $23^\circ 28' 20''$:: *sine* $36' 46''$: *sine* $20' 36'' = RPS$; whence ZPS , turned into time, $= 2' 27'' 4'''$, and $RPS = 1' 22'' 24'''$, and the error at the summer solstice is $3' 49'' 28'''$; at the equinoxes $2' 27'' 4'''$; at the winter solstice $1' 4'' 40'''$.

139. *Scholium.* With respect to those stars that pass the great circle $ASZa$ (fig. 2.) twice in one revolution, it may be observed, 1st. That when the point of intersection Z falls between P and E , (that is between the elevated pole and the equator) the hour angle ZPR , at the upper transit is the difference of the angles ZPS and RPS , but the hour angle zPr , at the under transit is the sum of the respectively equal angles zPs and rPs . Contrarywise, when the point Z falls between E and M , or P and m , (that is below the pole or below the equator,) then the hour angle ZPR , at the upper transit is the sum, and at the under transit the difference of the aforesaid angles ZPS and RPS .

2^{dly}. If PR be less than PZ , (fig. 2.) both transits will fall on the same side of the meridian, and RPS is greater than ZPS ; if PR be greater than PZ , (fig. 3.) the transits will be on contrary sides of the meridian, and RPS is less than ZPS .

3^{dly}. Let the hour circle SPs (fig. 2.) cut the parallel of declination in Q and q , and because it bisects it, making the arches QR and qr equal, the difference between the two intervals of time which the star takes in describing the two segments $RQqr$, and rR , is four times what it takes in describing the part QR , which measures (on that parallel) the hour angle RPS , and conversely $\frac{1}{4}$ of the difference of the two intervals of time between the transits will give the hour angle RPS , allowing as before 360 degrees for the time of one revolution of the stars, as shown by the clock.

PROBLEM II.

140. **A**LL things as in par. 131, let the arches PZ , PR , and the perpendicular PV be given, to find the hour angle ZPR .

In the right angled triangle VPZ we have *rad.* : *cotan.* PZ :: *tan.* PV : (*cosine* $VPZ =$) *sine* ZPS . Again, in the right angled triangle VPR

V P R we have $rad. : cotan. PR :: tan. PV : (cosine V P R =) sine R P S$, and the sum or difference of R P S and Z P S = Z P R the hour angle sought.

Otherwise thus, Z P S being found by the first analogy, R P S may be found from it by the analogy before given at the end of par. 131, namely $cotan. P Z : cotan. P R :: sine Z P S : sine R P S$, whence Z P R as before.

P R O B L E M III.

141. **L** E T A S Z a (fig. 5.) represent the great circle described in the heavens by the line of collimation of the transit telescope continued, cutting the several circles of the sphere as in par. 131. Given the distance of the intersection of this circle and the meridian from the pole, that is the arch P Z, together with the times of the observed transits of a known star above and below the pole; to find the angle P Z R or E Z S, in which the circle A Z a intersects the meridian.

Solution 1. From the times of the observed transits we get the angle R P S, by the rule in par. 139; but the polar distances P Z and P R are also given, whence the angles Z P S, and E Z S, may be had by inverting the analogies given in par. 131.

142. *Scholium*. If the axis of the telescope be exactly level, the point Z falls in the zenith, (fig. 1, 2, 3.) the arch P Z will be the complement of latitude, and the angle E Z S the error of the instrument in azimuth, which will therefore be found by inverting the analogies in par. 134. If the axis be exactly east and west, the point Z falls in the horizon, (fig. 4.) the arch P Z will be the latitude, and the angle E Z S the error in the level of the axis.

Example. Let the transit of *Capella* (whose declination is $45^{\circ} 43' 40''$) be observed under the pole at VIII^h 1' 58", above the pole at XIX^h 55' 58", and again the next day under the pole at VIII^h 0' 0". Suppose now the axis of the instrument to be exactly level, what is the error in azimuth?

Here the time of the revolution of the stars, as shown by the clock is $23^h 58' 2''$, the clock gaining 1' 58" upon mean solar time. The two intervals of time between the transits are $11^h 54' 0''$ and $12^h 4' 2''$, the difference of these intervals is $10' 2''$; $\frac{1}{4}$ of this difference is $2' 30''\frac{1}{2}$, which turned into minutes and seconds of a degree, at the rate of 360° for $23^h 58' 2''$ gives $R P S = 37' 40''\frac{1}{2}$, and Z being in the zenith, we have by inverting the analogies in par. 134. $\tan. dec. : \tan. lat. :: sine R P S : sine Z P S$; and again, $sine lat. : rad. :: \tan. Z P S : \tan. E Z S$; that is in this example, $\tan. 45^{\circ} 43' 40'' : \tan. 52^{\circ} 13' :: sine 37' 40''\frac{1}{2} : sine$

$47' 22'',8 = ZPS$; again, $\text{fine } 52^\circ 13' : \text{rad.} :: \tan. 47' 22'',8 : \tan. 59' 56'',8 = EZS$ the error in azimuth.

Cor. 1. Hence we get the angle ZPR being the sum or difference of RPS and ZPS , by par. 139. This angle ZPR turned into time gives the difference between the time of the observed transit of the star and the time of its passage over the true meridian, that is the error in the transit of the star. In the example before proposed, $ZPS - RPS = 9' 42'',3$ which turned into time at the rate of $23^h 58' 2''$ for 360° , is $38''\frac{3}{4}$, and $ZPS + RPS = 1^\circ 25' 3'',3$, which turned into time, as before, is $5' 9''\frac{3}{4}$. Now because the interval of time wherein the star described the eastern part of its parallel is in this example less than the other interval wherein it described the western part; therefore the error of the telescope in azimuth is to the west of the south. Hence on the day of observation *Capella* passed the true meridian below the pole at $VII^h 56' 18''\frac{1}{4}$, above the pole at $XIX^h 55' 19''\frac{1}{4}$, and again the next day below the pole at $VII^h 54' 20''\frac{1}{4}$, according to the time shown by the clock.

Cor. 2. The error in the transits of equatorial stars is $ZPS = 47' 22'',8$, which turned into time as before is $3' 9''\frac{1}{4}$.

143. *Solution 2.* Otherwise from the angle RPS , and polar distance PR given, we may find the perpendicular PV , and from thence the angle PZR , thus, In the right angled triangle $VP R$ we have $\text{rad.} : \tan. PR :: (\text{cosine } VPR =) \text{fine } RPS : \tan. PV$. Also in the right angled triangle VPZ we have $\text{fine } PZ : \text{rad.} :: \text{fine } PV : \text{fine } PZV = EZS$. These analogies when Z is in the zenith become $\text{rad.} : \tan. PR :: \text{fine } RPS : \tan. PV$. And $\text{cosine lat.} : \text{rad.} :: \text{fine } PV : \text{fine } PZR$.

Scholium. The former solution of the problem gives in the course of the work, the angles ZPR and ZPS as before; the latter solution gives the perpendicular PV , which is found by the first analogy from the given polar distance PR , and the angle RPS , derived from the observed upper and under transits of the star.

144. *Cor. 1.* The perpendicular PV being given, if the distance PZ varies, the sine of the angle PZV will be reciprocally as the sine of the hypotenuse PZ : Having therefore found the angle $PZV = EZS$ for one distance PZ , we may find it for any other by that proportion.

Example. All things as before, suppose the axis of the instrument to be exactly east and west, and the error to be wholly in the level, what is the quantity of this error?

In this case Z (fig. 4.) falling in the horizon, PZ becomes the latitude, and we have $\text{fine lat.} : \text{cosine lat.} :: \text{fine } EZS \text{ in the former case, to fine } EZS \text{ in the latter, but } EZS \text{ in the former example was found to be}$

59' 56",8, therefore had the error been wholly in the level of the axis it would have been 46' 28".

145. *Cor. 2.* The position of the axis of the transit telescope remaining unchanged, whatever its error be, the perpendicular P V will be given: In this case, if P R varies, the cosine of the angle V P R will be reciprocally as the tangent of the hypotenuse P R. (See par. 132.)

Hence in different stars the sines of the angles R P S are as the tangents of their declinations; consequently when the angle R P S is small, the differences of the intervals of time between their upper and under transits, will be as the tangents of the declinations of those stars.

P R O B L E M IV.

146. **T**O find the error in the position of a transit telescope, both in azimuth and in the level of its axis, from astronomical observations of the following sorts.*

First. Let the times of the observed transits of some star, both above and below the pole, be given as before; from which we may obtain the angle R P S by the rule in par. 139.

Secondly. Let corresponding altitudes of that star be observed, so that from thence we may find the time of its passage over the meridian; then the difference between the time of the passage of this star over the true meridian and the time of its passage observed by the transit telescope, (that is the error in the transit of the star) will give the angle R P Z.

Lastly. Suppose either the declination of the star, or its polar distance P R to be given.

Let A S Z a (fig. 5.) represent as before, the circle described in the heavens by the telescope, and let X be the zenith, then we shall have given the angles R P S, R P Z, and the arch P R, to find the arch A M, and angle Z A X.

Now $R P S \pm R P Z = Z P S$, whence inverting the former analogies in par. 131. we have $\text{fine } R P S : \text{fine } Z P S :: \text{cotan. } P R : \text{cotan. } P Z$, or $\text{tangent of declination} : \text{tan. } Z E$. To E M the complement of latitude add or subtract Z E, and we have Z M, but in the right angled triangles S Z E, A Z M, having the angle at Z common, we have $\text{fine } Z E : \text{fine } Z M :: \text{tan. } S E \text{ (the measure of } Z P S) : \text{tan. } A M$ the error in azimuth. Again, in the right angled triangle A Z M, we have $\text{rad.} : \text{cotan. } Z M :: \text{fine } A M : (\text{cotan. } Z A M =) \text{tan. } Z A X$ the error in the level.

147. *Ex-*

* The error in the position of a transit telescope may be determined by several other kinds of astronomical observations, as well as those here selected. See *De la Lande's* astronomy, Art. 2086.

147. *Example.* Let the transit of *Capella* be observed under the pole at $\text{VIII}^{\text{h}} 3' 56''$, above the pole at $\text{XIX}^{\text{h}} 53' 43''\frac{1}{4}$, and again the next day under the pole at $\text{VIII}^{\text{h}} 0' 0''$, the clock keeping mean solar time; and suppose it appears by taking corresponding altitudes that *Capella* passed the true meridian at $\text{XIX}^{\text{h}} 55' 54''\frac{3}{4}$, then to determine the error in the position of the transit telescope we have the two intervals of time between the transits $11^{\text{h}} 49' 47''\frac{1}{4}$ and $12^{\text{h}} 6' 16''\frac{3}{4}$, whose difference is $16' 29''\frac{1}{2}$; $\frac{1}{4}$ of this difference is $4' 7''\frac{3}{8}$, which turned into minutes and seconds of a degree, by the table in the *Connoissance des mouvemens Célestes*, gives $1^{\circ} 2' 1''$, for the angle R P S. Also from the time of the passage of this star over the true meridian compared with the time of its passage by the transit telescope, it appears that its transit seen in the telescope happened too early, the error in the transit being $2' 11''\frac{1}{2}$ of time, which turned into minutes and seconds of a degree as before, gives $32' 58''$ for the angle R P Z, whence $\text{R P S} - \text{R P Z} = \text{Z P S} = 29' 3''$. Therefore $\text{fine } 1^{\circ} 2' 1'' : \text{fine } 29' 3'' :: \text{tan. } 45^{\circ} 43' 40'' \text{ tan. } 25^{\circ} 40' 10'' = \text{Z E}$, whence $\text{Z E} + \text{E M} = 25^{\circ} 40' 10'' + 37^{\circ} 47' = 63^{\circ} 27' 10'' = \text{Z M}$. Also, $\text{fine } 25^{\circ} 40' 10'' : \text{fine } 63^{\circ} 27' 10'' :: \text{tan. } 29' 3'' : \text{tan. } 59' 59''\frac{1}{2} = \text{A M}$ the error in the azimuth. Again $\text{rad.} : \text{cotan. } 63^{\circ} 27' 10'' :: \text{fine } 59' 59''\frac{1}{2} : \text{tan. } 29' 58'' = \text{A Z X}$ the error in the level.

The perpendicular P V will be found by par. 143. $= 1^{\circ} 0' 27''$.

148. *Cor. 1.* The error in the transits of equatorial stars is Z P S or E P S $= 29' 3''$, which turned into time as before is $1' 55''\frac{7}{8}$. The error in the transit of stars whose declination is equal to Z E $= 25^{\circ} 40' 10''$ is nothing.

149. *Cor. 2.* The sine of the error in azimuth is to the tangent of the error in the level, as radius to (cotan. Z M $=$) tan. Z X, the distance of the point Z from the zenith X; or it is as the sine of Z M, the distance of the point Z from the horizon, to the sine of Z X, its distance from the zenith.

Scholium. A perpendicular let fall from the zenith X on the great circle A S Z a, measures the error of the level: If this perpendicular falls on the eastern side of the meridian, then the eastern end of the axis of the transit telescope is lowest, if it falls on the western side of the meridian, then the western end of that axis is lowest,

PROBLEM V.

150. **A**LL other things as in the foregoing problem, instead of the declination of the star, let P V, the perpendicular distance of the circle A S Z a from the pole be given, to find from thence the errors in the position of the transit telescope as before.

Here

Here in the right angled triangle VPZ we have ($\cosine VPZ =$) $\sin ZPS : \tan. PV :: rad. : \tan. PZ$, whose complement is ZE . The rest as in the foregoing problem.

Otherwise the solution may be continued thus: In the right angled triangles SZE , AZM , having the angle at Z common, we have $\cosine ZE : \cosine ZM :: \cosine ZSE : \cosine ZAM$, that is $\sin PZ : \sin ZX :: \sin ZSP$, (*whose measure is PV*) : $\sin ZAX$ the error in the level. Again, in the right angled triangle AZM , we have $rad. : \tan. ZM :: \tan. ZAX : \sin AM$, the error in azimuth.

151. *Scholium to prob. IV. & V.* It is not necessary that the star whose corresponding altitudes are to be observed should be the same with that whose upper and under transits are taken; and indeed this is seldom convenient. For the passage of a circumpolar star over the true meridian may be derived from the passage of any other star whose corresponding altitudes can be more conveniently taken, if the difference of their apparent right ascensions be sufficiently known; otherwise any error in the difference of their right ascensions will occasion an equal error in the passage of the circumpolar star determined therefrom. It may therefore be better to find the angle ZPS in another method, from the declinations or polar distances of these stars, wherein an error of a few minutes will not sensibly affect the conclusion.

Let R be the observed circumpolar star as before, T the star whose passage over the meridian is determined by corresponding altitudes; from the time of this star's passage so determined, compared with its transit seen in the telescope, we get the error in its transit, and from thence the angle TPZ ; then in problem the fourth, where the polar distance PR is given, we have $\tan. PT : \tan. PR :: \sin RPS : \sin TPS$. But $TPS \pm TPZ = ZPS$, whence the rest as in par. 146. In problem the fifth, where the perpendicular distance PV is given, in the right angled triangle $VP T$ we have $rad. : \cotan. PT :: \tan. PV : (\cosine TPV) \sin TPS$ and $TPS \pm TPZ = ZPS$ as before.

Example. Let the transit of *Capella* under the pole be at $VIII^h 3' 56''$, above the pole at $XIX^h 53' 43''\frac{1}{4}$; and again under the pole at $VIII^o 0' 0''$ as in par. 147. Suppose now the transit of α *Pegasi* (whose declination is $13^\circ 57' 20''$) to have been observed in the telescope at $XIII^h 51' 28''$, and let the time of its passage over the true meridian determined by corresponding altitudes be at $XIII^h 50' 32''$, to find from thence the error in the position of the transit telescope.

The angle RPS before found par. 147. from the upper and under transits of *Capella* was $1^\circ 2' 1''$, and the perpendicular distance PV was

$1^{\circ} 0' 27''$, therefore $rad. : tan. 13^{\circ} 57' 20'' :: tan. 1^{\circ} 0' 27'' : sine 0^{\circ} 15' 1''$, $2 = T P S$, now the error in the transit of α *Pegasi* is 56 seconds of time, which turned into minutes and seconds of a degree as before, gives $0^{\circ} 14' 1''$, 8 for the angle $T P Z$, and the transit seen in the telescope happening later than the transit over the true meridian, we have $T P S + T P Z = Z P S = 0^{\circ} 29' 3''$ as before. Now by par. 150, $sine 0^{\circ} 29' 3'' : tan. 1^{\circ} 0' 27'' :: rad. : tan. 64^{\circ} 19' 50''$, $= P Z$ whose complement $25^{\circ} 40' 10'' = Z E$. Again $sine 64^{\circ} 19' 50'' : sine 26^{\circ} 32' 50'' :: sine 1^{\circ} 0' 27'' : sine 29' 58'' = Z A X$ the error in the level. Lastly, $rad. : tan. 63^{\circ} 27' 10'' :: tan. 29' 58'' : sine 1^{\circ} 0' 0'' = A M$ the error in the azimuth.

152. *Of transits taken by reflection from the surface of fluids.*

In the projection of the sphere on the plane of the prime vertical (fig. 6.) let $T A s$ be a portion of the great circle which the transit telescope continued describes in the heavens, cutting the horizon $A H$ in A . Now the reflecting surface will present to our view a concave surface below the horizon, similar to that above; in this let s be the image of the sun seen through the telescope; through s draw an azimuth circle $s H S$, (part below and part above the horizon,) and take the arch $H S = H s$, and S will be the place of the real sun in the upper concave, when its image is seen at s in the lower concave. In like manner may be found the places of all those objects whose images are seen in the great circle $A s$; which will all lie in the great circle $A S$, intersecting the horizon in A , and making the angle $S A H = s A H$; thus all objects seen by reflection through the transit telescope while it describes the arch $A s$ below the horizon, will really be in the arch $A S$ above it. Let $M M$ be the meridian, intersecting the horizon in M , and $Z A$ an azimuth circle passing through A , then is the arch $M A$, the error of the transit telescope in azimuth, the angle $Z A S = Z A T$ the error in the level of the axis, whence the position of the great circle $A S$, or the *reflected path* of the transit telescope, will be known.

153. In fig. 5. let $A B C a$ be the direct path of the transit telescope cutting the meridian in C ; let $A S Z a$ be the reflected path, cutting the meridian in Z , and let X be the zenith, then because $a m = A M$, and $C a m = Z A M$, the right angled triangles $a C m$, $A Z M$, will be equal, and $c m = Z M$, and $a C m = A Z M$, whence $C X = Z X$, and $A C M = A Z M$, and thus the direct and reflected path will cut the meridian at equal angles, and at equal distances from the zenith, but on contrary sides. If then out of these four quantities, *viz.* the error of the transit telescope in azimuth, the error of the axis in level; the point where the direct path cuts the meridian, and angle of intersection, any two are given, the position of the reflected path will be known, and the time of the reflected transit may be determined by the methods before laid down.

P R O B L E M S

RELATING TO

P E N D U L U M S,

AND THEIR

A P P L I C A T I O N T O C L O C K S.

P R O B L E M I.

154. **H**AVING the error of a clock, or what it gains or loses in a given time, to find how much the pendulum must be lengthened or shortened to correct that error.

Let l be the length of such a pendulum as is requisite to make the clock go true, t the given time of observation, e the error of the clock, d the quantity by which the pendulum of the clock must be lengthened or shortened to correct that error, that is, to make the length of the pendulum of the clock become l . Now if the pendulum must be ^{lengthened} _{shortened} by the quantity d , that its length may become l , then its present length is $l \mp d$; moreover the number of vibrations performed in the given time t is shown by the apparent motion of the hands during that time, hence the number of vibrations that would be performed in the time t if the length of the pendulum were l , is to the number performed in the same time t , when its length is $l \mp d$, as t is to $t \pm e$ if the clock gains _{loses}; but the time of one vibration is reciprocally as the number of vibrations performed in a given time, therefore the time of one vibration in the former case is to the time of one vibration in the latter as $t \pm e$ to t . Again, The lengths of pendulums are to one another in a duplicate ratio of the times of their vibrations, therefore l is to $l \mp d$, in a duplicate ratio of $t \mp e$ to t , that is $l : l \mp d :: t \pm e^2 : t^2$, whence by conversion

$$d :: t \pm e^2 : \begin{cases} t + e^2 - t^2 = 2te + ee & \text{if the clock gains.} \\ t^2 - t - e^2 = 2te - ee & \text{if the clock loses,} \end{cases}$$

$$\text{and } d = \frac{2te \pm ee}{t \pm e^2} \times l = \frac{2e}{t} \mp \frac{3e^2}{t^2} + \frac{4e^3}{t^3} \mp \frac{5e^4}{t^4} \&c. \times l$$

The foregoing series may be divided into two; the former consisting of
U al-

alternate terms $\frac{2e}{t} + \frac{4e^3}{t^3} + \frac{6e^5}{t^5} \&c.$ $\times l$, the latter of the other alter-

nate terms $\frac{3e^2}{t^2} + \frac{5e^4}{t^4} + \frac{7e^6}{t^6} \&c.$ $\times l$ which is to be subtracted from added to

the former series, if the clock gains loses. The former series, which is the mean value of d , may be conveniently expressed in the following manner, in which the capital letters denote whole terms as they arise.

$$\frac{l \times e}{\frac{1}{2}t} + \frac{e^2}{\frac{1}{2}t^2} A + \frac{e^2}{\frac{2}{3}t^2} C + \frac{e^2}{\frac{3}{4}t^2} E \&c.$$

the other series thus $\frac{l \times e^2}{\frac{1}{3}t^2} + \frac{e^2}{\frac{3}{5}t^2} B + \frac{e^2}{\frac{5}{7}t^2} D \&c.$

155. *Example 1.* Put $l = 39,2$ inches, $t = 24$ hours or 1440 minutes, $e =$ one minute, then

$$\frac{1}{2}t = 720 = 8 \times 9 \times 10) 39,2$$

$$tt = 2073600 \quad 8) 3,92$$

$$9) 0,49$$

$$\frac{1}{2}tt = 1036800) \quad 0,0544444444 = A$$

$$0,0000000525 = C$$

$$\text{mean value of } d = 0,0544444969 = A + C$$

$$\frac{1}{3}tt = 691200) 39,2000000000$$

$$0,0000567125 = B$$

$$\text{when the clock gains, } d = 0,0543877844 = A - B + C$$

$$\text{when the clock loses, } d = 0,0545012094 = A + B + C$$

156. *Example 2.* Put $l = 39,2$ inches, $t = 24$ hours or 86400 seconds, $e =$ one second.

$$\frac{1}{2}t = 43200 = 8 \times 9 \times 6 \times 100) 39,2$$

$$8) 0,392$$

$$9) 0,049$$

$$6) 0,00544444444444$$

$$\frac{1}{2}tt = 3732480000) \quad 0,00090740740740 = A$$

$$0,00000000000024 = C$$

$$\text{mean value of } d = 0,00090740740764 = A + C^*$$

$\frac{1}{3}tt$

* The logarithm of $A + C$ in this case = $-4,9578024$.

$$\frac{1}{2}tt \left\{ \begin{array}{l} = 2488320000 \\ = 4 \times 4 \times 8 \times 8 \times 3 \times 9 \times 9 \times 10000 \end{array} \right\} 39,2$$

$$4) 0,00392$$

$$4) 0,00098$$

$$8) 0,000245$$

$$8) 0,000030625$$

$$3) 0,000003828125$$

$$9) 0,00000127604166$$

$$9) 0,00000014178240$$

$$0,00000001575360 = B$$

If the clock gains $d = 0,00090739165404 = A - B + C$

If the clock loses $d = 0,00090742316124 = A + B + C$

As the two first terms of the foregoing series give the value of d , correct to 7 places of decimals in the former example, and 12 in the latter, it seems as easy and more exact than any other method. See *Saunderson's Algebra*, Art. 298.

157. *Cor.* The quantity d is accurately as l , and very nearly as $\frac{e}{t}$ whence t being given, e is as $\frac{d}{l}$: let d now represent the change in the length of any meteline pendulum rod, arising from a given change of heat or cold; then in rods made of the same metal, but of different lengths, d will be as l , and therefore e will be a given quantity; that is, in clocks whose pendulum-rods are made of the same metal, the error occasioned by the fore-mentioned change will be the same, whatever be the length of the pendulum.

158. The error in 24 hours, arising from a change of one degree of heat or cold, according to *Farenheit's* scale, in pendulums whose rods are made of the following metals, is as under:*

	Seconds.
Blistered steel	0,276
Iron	0,302
Cast brass	0,450
Brass wire	0,464

This error will be increased in proportion to the number of degrees by which the heat or cold is changed, in *Farenheit's* thermometer.

If the rod be made of two sorts of metal, the error will be proportionable to the part made of each; thus, if half the length be steel, and half cast brass, the error for one degree of heat in the former is 0,138 seconds, for the latter 0,225 seconds, for both 0,363 seconds in a day: And for 10 degrees of heat 3,63 seconds in a day.

P R O B-

* According to Mr. *Smeaton's* table of the expansion of metals. *Phil. Trans.* v. 48. 1754.

P R O B L E M II.

159. **T**O find the centrifugal force of the ball of a pendulum at the lowest point, where that force is the greatest.

RULE. As radius is to the versed sine of the arch which the pendulum describes on each side of the lowest point; so is double the weight of the ball, to the centrifugal force required.

Demonstration. If the velocity of the ball at the lowest point were such as it would acquire by falling through half the length of the pendulum, then the centrifugal force of the ball would be equal to its gravity;* but the velocity of the ball at the lowest point is such as it would acquire by falling through the versed sine of the arch described in its descent.† Now the centrifugal force of a body moving in a circle, is in a duplicate ratio of its velocity,* therefore the gravity of the ball, is to its centrifugal force at the lowest point, as the square of the velocity it would acquire by falling through half the length of the pendulum, to the square of the velocity it would acquire by falling through the versed sine of the arch described in its descent, or the arch through which it vibrates on each side the lowest point. But by the laws of falling bodies, the squares of the velocities they acquire in falling are as the spaces descended through. We have therefore the gravity of the ball, to its centrifugal force at the lowest point; as half the length of the pendulum, to the versed sine of the arch described on each side the lowest point, or (doubling the antecedents) we have double the weight of the ball, to its centrifugal force at the lowest point, as the whole length of the pendulum to the versed sine of the arch which the pendulum describes on each side the lowest point; whence, if we take the length of the pendulum for the *tabular radius*, the rule is manifest.

Scholium. If to the centrifugal force of the ball found as before, we add the weight of the ball itself, we shall have the whole tension of the rod when the ball is at the lowest point, where that tension is greatest.

Example. Let the ball weigh 6 pounds, or 96 ounces, and let it swing 4 degrees on each side the perpendicular, then we have *radius : versed sine of 4° :: 19202. : 0,4677* parts of an ounce, to which if the weight of the ball be added, we have the greatest tension of the rod = 6 lb. 0,4677 oz.

Cor. I. If the angular distance through which the pendulum vibrates on each side of the perpendicular, and the weight of the ball be given, its centrifugal force at the lowest point will be the same, whatever be the length of the pendulum.

Cor.

* *Newt. Princip. L. I. prop. 4, and cor. 9. — Huygens De vi centrifuga.*

† *Huygens De descensu gravium, prop. 8.*

Cor. 2. If the pendulum describes an arch of 60 degrees on each side the perpendicular, the centrifugal force at the lowest point will be equal to the weight of the ball. If the arch so described be 90 degrees, the centrifugal force will then be double the weight of the ball, and the whole tension at the lowest point will be triple the weight of the ball. Lastly, if the pendulum describes an arch of 180 degrees on each side the lowest point, descending from the highest point of the circle, and ascending up to it again, then the tension of the rod at the lowest point will be 5 times the weight of the ball. If the motion of a church bell in ringing resembles that of a pendulum, as in some degree it does, then the gudgeons must be able to bear 5 times the dead weight of the bell, to sustain its weight and centrifugal force together, when the bell is rung up so as to set.

PROBLEM III.

160. **T**O correct the going of a clock by a small bob or regulator below the ball

Let A be the weight of the pendulum rod, a its length, B the weight of the ball, b its distance from the point of suspension, C the weight of the regulator, c its distance from the point of suspension. To find l the distance of the center of oscillation of the whole compound pendulum from the point of suspension.

The known rule for finding the center of oscillation in all cases is this :

If each particle of a compound pendulum be multiplied into the square of its distance from the axis of suspension, and the sum of all these products be divided by the sum of all the products which arise by multiplying each particle into its distance from the axis of suspension, the quotient will be the distance of the center of oscillation from the axis of suspension.

Now in the rod whose thickness is uniform, and which may be considered as a line, the sum of all the former products is $\frac{1}{3} a a A$, the sum of all the latter $\frac{1}{2} a A$. In the ball, (considered as a point,) the sum of all the former products is $b b B$, of all the latter $b B$; In the regulator the former sum is $c c C$, the latter is $c C$, wherefore
$$\frac{\frac{1}{3} a a A + b b B + c c C}{\frac{1}{2} a A + b B + c C} = l$$

161. For the sake of simplicity, let a always $= b$, that is, let the rod extend no farther than the ball, and first suppose $C = 0$, and then we have the center of oscillation of the rod and ball only
$$= \frac{\frac{1}{3} a a A + a a B}{\frac{1}{2} a A + a B}$$

$$= \frac{\frac{1}{3} A + B}{\frac{1}{2} A + B} \times a = l$$
 the length of the isochronous simple pendulum :

or

or if l the length of a simple pendulum be given, then we have $\frac{1}{3}A + B : \frac{1}{2}A + B :: l : a$, the length of the isochronous pendulum compounded of the rod A and ball B ; whence $\frac{1}{3}A + B : \frac{1}{6}A :: l : a - l$, that is, *The weight of the ball with a third part of the weight of the rod, is to a sixth part of the weight of the rod, as the length of a given simple pendulum, to the increase of that length in the isochronous compound pendulum, on account of the weight of the rod.*

Example. Put $l = 39,2$ inches, that is let the pendulum vibrate seconds, put $A = 6$ ounces, $B = 6$ pounds, or 96 ounces, and we have $\frac{1}{3}A + B = 98$, and $\frac{1}{6}A = 1$; therefore $98 : 1 :: 39,2 : 0,4$ of an inch for the increase of length occasioned by the weight of the rod, which added to 39,2 gives 39,6 inches, the whole length from the point of suspension to the center of oscillation.

162. Let γ be the quantity by which a simple pendulum whose length is l , must be altered to make it gain or lose some small matter, for instance a second in 24 hours, let $\dot{a}$ be the corresponding alteration in the length of the compound pendulum, then is $\frac{1}{3}A + B : \frac{1}{2}A + B :: \gamma : \dot{a}$. Now when l is 39,2 inches γ was before found* = 0,000907407, therefore in this instance $\dot{a} = 0,000916667$ inches.

163. In the pendulum compounded of a rod, ball, and regulator, putting $a = b$ as before, we have from the general theorem par, 160.

$$\text{Theorem first, } \frac{a a \times \frac{1}{3}A + B + c c C}{a \times \frac{1}{2}A + B + c C} = l$$

Put now $\frac{1}{2}A + B = P$; $\frac{1}{3}A + B = Q$, and $\frac{P}{Q}l$ (or the length of a pendulum compounded of the rod and ball only, isochronous to the whole $\dagger$) = R . Put likewise $\frac{c - l \times c C}{Q} = S$, $\frac{R - a \times Q \times a}{C} = T$, and we have the following theorems:

$$\text{Theorem 2. } a = \frac{1}{2}R \pm \sqrt{\frac{R R}{4} - S}$$

$$\text{Theorem 3. } c = \frac{1}{2}l \pm \sqrt{\frac{l l}{4} + T}$$

$$\text{Theorem 4. } C = \frac{R - a \times Q \times a}{c - l \times c}$$

164. In the second theorem c is always supposed greater than l , and therefore S affirmative and likewise less than $\frac{R R}{4}$ $\ddagger$ whence there

* Par. 156. $\dagger$ By par. 161. $\ddagger$ Otherwise the quantity a would be impossible.

there will be two affirmative values of a the distance of the ball, and there are two points at either of which if the ball be placed, the whole will be isochronous to a simple pendulum whose length is l . These points are each equally distant from the middle of R , the length of an isochronous pendulum, composed of the rod and ball only. One of these points falling very near the point of suspension, if the ball were placed there, the accelerating force of gravity on the pendulum would be greatly lessened, and the power of the pendulum in regulating the clock, or (as Mr. *Harrison* calls it) *its dominion** much weakened, the regulator in effect becoming the ball; this value therefore is to be rejected.

165. In the third theorem, if R be less than a , that is if l be less than $\frac{Q}{P} a$, or if the length of the simple pendulum isochronous to the whole, be assumed less than that which is isochronous to the pendulum composed of the rod and ball only, then T will be negative, and c be less than l ; that is if the time of a vibration be supposed to be lessened by the addition of the regulator, it must then be placed above the ball; in which case the pendulum will be equally accelerated if the regulator be equally distant from the middle of the length l , and the quantity of acceleration will be greatest when the regulator is in the middle point. This is the case which *Huygens* chiefly considers; but it is inconvenient in practice to have the regulator above the ball, in pendulums whose rods are either made of wood or compounded of different metals.

166. In these four theorems, the quantities B and C , a and c , may be interchanged for each other; that is, we may change names, and call the regulator the ball, and the ball the regulator. Only it must be observed that in this case the rod must be supposed to extend to the regulator, that now taking the place of the ball.

167. From the foregoing theorem† $\frac{aa \times \frac{1}{3} A + B + cc C}{a \times \frac{1}{2} A + B + c C}$ or $\frac{aaQ + ccC}{aP + cC} = l$

we have *Step 1.* $aaQ + ccC = aPl + cCl$ whence

Step 2. $2c \dot{c} C = aP \dot{l} + \dot{c} Cl + cC \dot{l}$ whence

Theorem 5. $2c - l \times C : a \times \frac{1}{2} A + B + cC :: \dot{l} : \dot{c}$

Wherefore if $\dot{l}$ as before, be the quantity by which a simple pendulum whose length is l , must be altered to make it gain or lose a second in a day, we have $\dot{c}$ the corresponding alteration in the place of the regulator of the compound pendulum; and if $\dot{c}$ thus found be equal to one interval of the thread of the screw that raises the regulator, then one turn of it will alter the clock a second in a day.

168. *Cor.*

* See the Principles of Mr. *Harrison's* Time-keeper, p. 20.

† Par. 163.

168. *Cor.* When C is small in respect of $\frac{1}{2}A + B$, and c does not much exceed a , (so that cC vanishes in respect of $a \times \frac{1}{2}A + B$) then i is inversely as $2c - l$, or if d be the excess of c above l , inversely as $l + 2d$. In such a case a cannot differ much from R , (for it equals R when C is nothing) and then we have $\overline{2c - l} \times C : R \times \frac{1}{2}A + B (= \frac{\frac{1}{2}A + B^2 \times l}{\frac{1}{3}A + B}) :: i$

i . If we further suppose the weight of the rod to vanish in respect of the ball; that is put $A = 0$, then theorem 5th becomes $\overline{l + 2d} \times C : B \times l :: i : i$, or i to i in a ratio compounded of $l + 2d$ to l , and C to B .

169. From the second step above we likewise get $\frac{2ic - il - c^2}{P \cdot i} \times C = a$, For $\frac{2ic - il - c^2}{P \cdot i}$ or rather for $\frac{2c - l}{P} \times \frac{i}{l} - \frac{c}{P}$, put X , and we have $CX = a$, which being substituted for a in the first step, after due reduction gives *Theorem 6.* $\frac{lPX - \overline{c - l} \times c}{QXX} = C$

170. *Cor.* If we reject the quantity $\overline{c - l} \times c$ as inconsiderable in respect of lPX , then $\frac{lPX}{QXX}$ or $\frac{R}{X} = C$; again take $X = \frac{2c - l}{P} \times \frac{i}{l}$ (neglecting $\frac{c}{P}$, which has a contrary effect on the value of C , to rejecting

$\overline{c - l} \times c$), and we have $\frac{R \times P}{2c - l} \times \frac{i}{c} = C$, or $\overline{2c - l} \times i : i ::$

$\frac{\frac{1}{2}A + B^2 \times l}{\frac{1}{3}A + B} : C$, agreeably to what we had before; and further supposing the weight of the rod to vanish in respect of the ball; then $\overline{2c - l} \times i : i :: B \times l : C$, that is B to C in a ratio compounded of $\overline{2c - l}$ or $l + 2d$ to l , and $i : i$.

171. From the foregoing theorem, if the weight of the rod and ball, the place of the regulator, and interval of one thread of the screw that raises the regulator be given, the weight of the regulator and place of the ball may be so determined that one turn of the screw shall alter the clock a second in a day, and that the whole shall be isochronous to a given simple pendulum. Of the use of this and the foregoing theorems we shall give an example.

172. Let the weight of the rod $A = 6$ ounces, the weight of the ball B , 96 ounces; the distance of the regulator from the point of suspension $c = 44,2$ inches; let the screw have 40 threads in an inch, therefore the in-

interval of one thread, or $\dot{c} = 0,025$; let the whole pendulum, compounded of the rod, ball, and regulator afore said, vibrate seconds, that is put $l = 39,2$ inches, and consequently $i = 0,000907407$,* then we have $P = \frac{1}{2}A + B = 99$, $Q = \frac{1}{3}A + B = 98$, $R = 39,6$,† $\frac{2c-l}{P} = 0,496969$, $\frac{\dot{c}}{i} = 27,551$, $\frac{c}{P} = 0,446464$, $\frac{2c-l}{P} \times \frac{\dot{c}}{i} = 13,69206$, $X = 13,2456$, $lPX = 51403,3$, $lPX - c - l \times c = 51182,33$, $QXX = 17193,54$, whence $C = 2,97683$ ounces, the weight of the regulator sought. On the first contraction we have $C = 2,89220$, on the second $C = 2,77622$.‡

173. From C thus determined we may find the place of the ball requisite to make the pendulum vibrate seconds, by the second theorem thus; $R = 39,6$, $c - l = 5$, $c = 44,2$, $C = 2,97683$, $Q = 98$, whence $S = 6,71305$, $\frac{RR}{4} = 392,04$, $\frac{RR}{4} - S = 385,327$ whose square root is $19,62973$, whence $a = 39,4297$ inches; the other value of a which is $0,22973$ is to be rejected for the reasons before given in par. 164.

174. To know what would be the place of the ball to make the pendulum vibrate seconds if the rod extended to the regulator, we must interchange the values of B and C , and of a and c , and find c by the third theorem. Let us suppose for the sake of simplicity, that the regulator is 3 ounces, all other circumstances as before; then we have $A = 6$, $B = 3$, $C = 96$, $a = 44,2$, whence $P = 6$, $Q = 5$, $R = 47,04$, $R - a = 2,84$, $T = 6,538$, $\frac{ll}{4} = 384,16$, $\frac{ll}{4} + T = 390,698$, whose square root is $19,766$, and $c = 39,366$ inches, scarcely differing from what we had before.

* By par. 156. All the circumstances in this example are taken from the pendulum described in par. 76, and the following ones.

† By par. 161.

‡ That the regulator may have the intended influence upon the pendulum, its weight should be something more than what this calculation gives it; because of the force of the spring and the weight of those parts of the rod which are not taken into the account.

P R O B L E M S

RELATING TO

C L O C K - W O R K.

Of the force of the swing wheel upon the paletts of a clock.

P R O B L E M I.

175. **I**N plate VIII, fig. 1. let C be the center of the swing wheel $E e$, whose radius is CE ; let A be the center round which the paletts move; PEL , pel the sections of the faces of the paletts, by the plane in which the swing wheel lies, that is by the plane of the figure;* also suppose the face of each palett to be a plane; and therefore PEL , pel , right lines. Let E be a tooth of the wheel acting against the face of the palett PEL , in the direction KE , perpendicular to the radius CE , and moving the palett in the direction EF , perpendicular to AE a radius drawn from A the center of motion to the point where the tooth acts upon the palett.

To find the proportion of the forces acting upon the tooth and palett in the directions KE , FE respectively, when those forces balance each other.

To find likewise the pressure upon the centers A and C , occasioned by the action of those forces when they balance each other.

The action of the tooth of the wheel in the direction KE , against the face of the palett, will (if the palett be sustained by the force FE) be accompanied with the reaction of the fixed center C in the direction CE ; for the tooth cannot press against the face of the palett without acting at the same time in the direction EC against the center C † whose reaction therefore will of necessity accompany the action of the tooth. Hence the known force upon the tooth in the direction KE , will be attended with another unknown force in the direction CE , and their combined action upon the face of the palett will occasion in it a tendency to move in the di-

* The faces of the paletts are always made perpendicular to the plane of the swing wheel.

† If the palett be sustained, the tooth cannot move forwards unless the radius EC be shortened; hence if the tooth be forced forwards in the direction KE , the radius EC will be compressed, and therefore act against the center C , in consequence of the force urging the tooth in the direction KE .

direction EB , perpendicular to the plane PEL upon which these forces act. Now if the plane PEL were perfectly at liberty to move in any direction, the united effort of the forces KE , CE , would carry it in the direction EB , and a single force impressed upon the plane in the contrary direction BE , *and in that only*, would counteract the other two forces and keep the plane in equilibrio: But the directions of these three forces being known, their proportions when they balance each other are likewise known by a common rule in mechanics. Having therefore drawn EB perpendicular to PE , produce CE to D , and draw BD parallel to KE , and ED , DB , BE , the sides of the triangle EDB , lying in the direction of the forces aforesaid, determine their proportions.

EB then represents the quantity and direction of the force immediately impressed on the plane PL by the action of the wheel and the consequent reaction of its center, but this plane is restrained from moving in the direction EB , and can move only in the direction EF , describing a circle round the center A . Therefore only part of the force EB will be employed in producing that circular motion; part will act against the center A in the direction EA , and be sustained by that center. Resolve then the force EB into the forces EF , FB (perpendicular and parallel to the radius AE ,) and the former will be the force urging the palett in the direction EF , and the latter the pressure on the center A . If therefore DB represent the force applied to the tooth E , FE will be that on the palett which balances it; DE will be the pressure upon the center of the wheel, and FB the pressure upon the center of the paletts.

From C let fall the perpendicular CL on the face of the palett, take $Ea = EC$, and let fall the perpendicular as ; then the right angled triangles CEL , aEs , having equal hypotenuses, are similar to the right angled triangles EBD , EBF , having one common hypotenuse; and DB , FE , DE , FB , are to each other as EL , Es , CL , as , therefore the two former will represent the forces to be applied to the wheel and palett; the two latter the pressure upon their respective centers; but the two former are the cosines, and the two latter the sines of the angles CEL , AEL , to the radius CE , whence their proportion is known if those angles be given.

176. The forces here estimated are those immediately applied to the wheel and palett at the point E ; but if the wheel and palett be acted upon by forces applied at right angles to equal radii drawn from their centers A and C , (as for instance by the forces of two weights hanging from equal barrels, one fixed upon the arbor of the wheel, and the other upon the

arbor of the paletts, which is the case we shall suppose*) then the force upon the wheel so applied, is to that upon the palett which balances it, in a ratio compounded of the former ratio of EL to Es , and of the ratio of the radius CE , to the radius AE . From A let fall the perpendicular AS upon PEL produced, and $CE : AE :: Ea : EA :: Es : ES$, therefore the force upon the wheel is to that upon the palett in a ratio compounded of EL to Es , and of Es to ES , or in the ratio of EL to ES , therefore if EL represent the force applied to the wheel in the manner just now mentioned, ES must be that upon the palett to balance it. †

177. *Scholium.* The teeth of the wheel continually moving forwards alternately give one palett a circular motion the same way with the wheel, and the other palett a circular motion contrary to the wheel; the nature of the thing requires this, that the force of the wheel may aid the alternate motion of the pendulum; the former of these PEL is called the *leading palett*, the latter pel the *driving palett*. Now the immediate effect of the action of the tooth against the face of the palett is to carry it in the direction EB perpendicular to its own plane: Therefore, that the wheel may give the leading palett a circular motion the same way with itself, this perpendicular EB must lie on the contrary side of the line EA , from the center C , that is the angle AES , (made by the radius of the leading palett with that part of its face to which the tooth is moving) must be acute: For a like reason the angle Aep (made by the radius of the driving palett with that part of its face which the tooth hath left) must be acute. Again the part of the face towards which the tooth is moving in each palett, must make an acute angle with the radius of the wheel; otherwise the tooth in moving forward would not act upon the palett but forsake it; that is the angles CEL , Cel , must be acute.

178. So far is necessary in all cases, but the mechanism of common paletts requires further, *first*, That the face of the leading palett should lie within the angle AEC , that is, if produced it should cut the line AC joining the centers of the wheel and paletts. *Secondly*, The face of the driving palett should lie without this angle. *Thirdly*, The radii of the two paletts AE , Ae , should be equal. We should always suppose these circumstances.

179. It

* In this case the velocity of the weights in descending will be directly as the angular velocity of the barrels round their axes. If it be admitted that these weights, when in equilibrio, must be to each other reciprocally as their velocities in the direction of the force of gravity; then the forces thus applied, and balancing each other, must be reciprocally as the angular velocities of the wheel and paletts.

† It may be proved that the angular velocity of the wheel is to that of the palett when they impel each other, as ES to EL , and therefore reciprocally as the forces upon each, when they balance.

179. It should be observed too, that the lines EL , ES , in the leading palett always lie in the same direction from E , but in the driving palett the corresponding lines el , ep , lie in contrary directions; therefore as the force on the leading palett moves it the same way with the wheel, that on the driving palett will move it the contrary way. Again, in the leading palett the lines CL , as lie on contrary sides of the face PS , but in the driving palett the corresponding lines lie on the same side; therefore because in the former case, the force upon the palett is of the same kind with that upon the wheel, *viz.* a pressure towards the center, in the latter it will be of a contrary kind, and pull from the center.

180. *Cor. 1.* From the equality of the radii of the paletts AE , Ae , and the equality of the radii of the wheel CE , Ce , it follows that AEC , AeC the internal angles formed by these radii at each palett are equal; and the sum of the two angles Aep , Cel , which the face of the driving palett makes with the two radii, Ae , Ce , is equal to AED the supplement, or external angle of the two radii AE , CE at the leading palett.

181. *Cor. 2.* When the face of the leading palett is perpendicular to AC the line joining the two centers, then $EL = ES$, that is the forces upon the wheel, and upon the leading palett are equal.

182. *Cor. 3.* Fig. 2. If the face of either palett (for instance the leading palett) makes equal angles with the two radii AE , CE , drawn from the centers A and C , then the triangles AES , CEL are similar, and $EL : ES :: CE : AE$; that is the force upon the wheel is to the force upon the palett, as the radius of the wheel to the radius of the palett.

183. *Cor. 4.* Fig. 3. Let AEC be a right angle, that is let the radius of the leading palett be a tangent to the wheel; produce CL until it intersects AE in m ; and $EL : ES :: Em : EA$, that is the force upon the wheel is to the force upon the palett as the tangent of ECm ($= AEL$) to the tangent of ECA .

PROBLEM II.

184. **G**IVEN the centers of the swing wheel and paletts, C and A , (fig. 1.) and the point E where the tooth meets the leading palett; to determine the position of the face of this palett so that the force upon the wheel shall be to the force upon the palett, (when they balance) in a given ratio; or so that the angular velocity of the wheel shall be to that of the palett in a given ratio, reciprocal of the former.*

Join the points E and A , on EA take Em to EA in the given ratio

* See the note on par. 176.

ratio of the force upon the wheel to the force upon the palett; join C and m, and through E draw E L perpendicular to C m, and it shall be the section of the face of the palett required.

For letting fall the perpendicular A S, we have $EL : ES :: Em : EA$; that is the force upon the wheel is to the force upon the palett in the ratio of E m to E A required.

185. *Method of Calculation.* In the triangle m E C, there are given the sides E m, E C and the angle m E C between them, whence we have the angles at the base, whose complements are those which the radii A E, C E, make with the face of the palett.

186. *Cor.* When the radius of the palett is a tangent to the wheel (fig. 3.) we have E m to E A, or the tangent of E C m = A E L to the tangent of the given angle A C E, in the given ratio of the force on the wheel to the force on the palett, whence A E L, or the angle which the face of the palett makes with its own radius is known, and the angle which it makes with the radius of the wheel or C E L, is the complement of the angle A E L.

PROBLEM III.

187. **G**IVEN the position of the face of the leading palett, to find the position of the face of the driving palett such that the force of the wheel upon each palett shall be equal.

Produce the perpendicular C L (fig. 1.) till it meets the radius A E in m, produce the radius C E, so that E c = E C, join c m, draw E n perpendicular to c m, make the angle A e p = A E n, and p e produced will be the section of the face of the driving palett required.

For from A and C let fall the perpendiculars A p, and C l on the face of the driving palett, and from A the perpendicular A t, on E n produced; then because A E t = A e p, and A E = A e, we have E t = e p; again, because c E n + A E t = A e p + C e l* and A E t = A e p, therefore c E n = C e l, but E c = E C = e C, whence E n = e l; but E t : E n :: E A : E m :: E S : E L, therefore e p : e l :: E S : E L; that is the force upon the driving palett is to the force of the wheel as the force upon the leading palett is to the same force of the wheel; therefore the force of the wheel upon each palett is equal.

188. *Cor. 1.* Fig. 2. If the face of the leading palett makes equal angles with the two radii A E, C E, the point m falls upon a, and the triangle m E c being isosceles m E n = c E n; and the angles which the face of the driving palett makes with the two radii A e, C e are likewise equal.

Cor.

* By par. 180.

189. *Cor. 2.* Fig. 3. If AEC , AeC be right angles, that is, if the radii of the paletts be tangents to the wheel, then $mEn = mEL$ and the angle Aep , which the face of the driving palett makes with its radius Ae , is equal to the angle AEL which the face of the leading palett makes with its radius AE .

190. *Method of Calculation.* In the triangle cEm (fig. 1.) the ratio of the sides Ec , Em , is given, being that of Ea to Em , or of Es to EL , or of the cosines of the angles AEL , CEL ; but cEm the angle at the vertex of the triangle cEm is also given, whence we have the angles at the base $Ec m$ and $Em c$, whose complements cEn and mEn are respectively equal to Cel and Aep the angles required.

Of the Escapement.

191. **W**HEN the clock is in going, the point of the tooth of the swing-wheel continually changes its place on the face of the palett as the pendulum vibrates: Hence the distance of E , (the part of the palett on which the tooth acts,) from the center A continually varies; and so likewise does the force of the wheel upon the palett, and the ratio of their angular velocities. The place of the tooth in the middle of its angular motion (reckoned forward) from beat to beat, or the middle between the place in which it first touches and that in which it finally leaves the palett, may be called the *mean* place of the tooth; the place of the palett at that time may be called the *mean* place of the palett; the distance AE the *mean* radius of the palett. And supposing the force upon the wheel to be given, the force then exerted upon the palett may be called the *mean* force of the wheel upon the palett; and the angular velocity of the palett, (supposing that of the wheel to be uniform) may be called the *mean* velocity of the palett. When these distances, forces or velocities are mentioned absolutely, their quantities in the mean position of the tooth and paletts, as before defined, are always to be understood. We shall also suppose the escapement to be made without any *drop*, or fall of the tooth, but that at the instant a tooth quits one palett, another tooth touches and begins to act upon the opposite palett. This indeed is possible in theory only, however in practice the closer the paletts are *scaped* (as the workmen call it) the less liable will the clock be, both to wear and to irregularities.

192. Let C , fig. 4. be the center of the wheel, A the center of the paletts, E the mean place of the tooth which acts upon the leading palett PEL ; e the mean place of the tooth which acts upon the driving palett pel ; join AC ,

A C, and because A E, A e are supposed equal,* A C will bisect the arch E e. Take the arches E G, E F, e g, e f, each equal to $\frac{1}{2}$ of an interval of the teeth of the wheel, and from the nature of an *escapement*, F will be the place of the tooth when it first touches the leading palett; G its place at leaving or *escaping* from under this palett, g the place of another tooth which strikes the driving palett at the instant the former tooth escapes; f is the place of the last mentioned tooth when it escapes from under the driving palett, F the place of a tooth (on the opposite side of the wheel) which at that instant strikes the leading palett. Again, with the center A, and radius A G = A g describe an arch cutting the paletts in L and l, and with the radius A F = A f, another arch cutting them in P and p; then will L be the point of the leading palett, from under which the tooth G escapes, l the dropping point of the other palett which comes down to meet the tooth g, and receives its blow, p the point of the palett, from under which this tooth escapes at f, and P the dropping point of the leading palett, which at the same instant receives the blow of the tooth F.

193. From what has been said it is evident that G and g are cotemporary places of two teeth of the wheel; namely that which escapes from the leading palett, and that which strikes the driving palett; therefore the arch G g contains some integral number of teeth; call that number n , and E e will contain $n + \frac{1}{2}$, and F f contain $n + 1$ teeth. Let the whole number of teeth in the wheel be N, and the arch E e will be $\frac{n + \frac{1}{2}}{N} \times 360$ degrees, half of which is the measure of the angle A C E. The angle A C E being thus determined, and the radius C E given, one of the other two sides A C, A E, or one of the other two angles of the triangle A C E must be also given, whence its other parts will be found. If A E C be a right angle, A C is the secant, and A E the tangent of A C E to the radius C E.†

194. The triangle A C E thus determined, if the position of the face of the

* Par. 178.

† That is, the secant and tangent of half the angle subtended at the center of the wheel by the number of teeth which the paletts take in, *with half a tooth over*. The author of the essay on clock-work gives a different rule, but cautiously lays down no principles on which to found it. It cannot be said therefore that the rule is *false*, but surely it is an *improper* one; for it supposes a line drawn from the center of the paletts to the tooth, *not in the middle of its action*, but *just when it leaves the leading palett*, to be a tangent to the wheel. See the figure in plate 2d of the essay, where T A K being a semicircle the angle at A is a right one.

The scheme in figure 3d, plate 3d, of the essay, intimated to be very comprehensive, exhibits no measures for all those cases in which the paletts take in an odd number of teeth, — Are such cases impossible?

See the Elements of Clock and Watch-work, by A. Cumming, paragraph 176, and the note upon it.

the leading palett be assumed, the ratio of the force upon the wheel to that upon the palett when they balance each other, or the reciprocal ratio of the angular velocity of the wheel to that of the paletts may be found by problem I, or the converse of this by problem II, and the position of the other palett by problem III. In the simpler cases, these circumstances may be easily determined by the corollaries.

195. *Example.* Fig. 3. Let the wheel have 30 teeth, and let the paletts take in ten of them; let the radii of the paletts be tangents to the wheel, let the wheel escape when the pendulum is one degree distant from its lowest point, and let the radius of the wheel be one inch. To determine the distance of the centers A and C, the radius A E, and the position of each palett.

Here $n = 10$, $N = 30$, $\frac{n + \frac{1}{2}}{N} \times 360^\circ = 126^\circ$, and $A C E = 63^\circ$, A C (the secant of 63° , to radius 1,) is 2,202, and A E (the tangent) is 1,962; moreover the arch E G, fig. 4. (or $\frac{1}{4}$ of an interval of the teeth) is 3 degrees, and G L by supposition one degree; * whence the cotemporary angular velocity of the wheel to that of the palett, (or the force on the palett to that on the wheel,) as 3 to 1; E m therefore (in fig. 3.) is $\frac{1}{3}$ of E A, or $\frac{1}{3}$ of the tangent of 63° , † equal to 0,6542035 = the tangent of $33^\circ 12' = E C m$, whence if we take the arch E T equal to twice $33^\circ 12' = 66^\circ 24'$, the chord E T produced will be the section of the face of the leading palett required; in like manner if we take the chord e t = E T, it will determine the position of the other palett. ‡

196. The foregoing example is taken from the common construction of paletts with the *dead beat*, in Mr. *Graham's* manner. Figure 4. exhibits the common construction of recoiling paletts, which take in seven teeth of the wheel, the whole number being 30. The radii of the paletts are tangents to the wheel; the face of the leading palett is made perpendicular, and that of the other palett parallel to the line joining the centers A and C. It follows therefore, that the mean force upon the paletts is equal to that of the wheel; || the mean angular velocities of the wheel and paletts are equal, and the cotemporary angles E C G, G A L, are nearly so, § therefore the pendulum ascends three degrees from its lowest point before the paletts escape.

197. In

* In strictness the cotemporary arches E G, G L, or rather the cotemporary angles E C G, G A L, are not the true measures of the mean angular velocities of the wheel and paletts; because while the wheel moves uniformly from E to G, the angular velocity of the palett continually increases, but the increase of the arch G L on that account is inconsiderable.

† Par. 186.

‡ Par. 189.

|| Par. 181.

§ Not exactly, because the motion of the paletts is not precisely uniform, supposing that of the wheel to be so. If we suppose the angular velocity of the wheel to be always the

197. In these examples we have considered both leading and driving paletts as planes; but supposing the former to be so, we shall find that if the driving palett passes through the point of contact e , (the radii AE, Ae , being tangents to the wheel as before,) and the escapement be without any drop, this palett must then be concave.

For from the center A , (fig. 4.) draw lines to the several points $PFG L$, $pfg l$, and since the sides AE and Ae , AL and Al , and also the angles EAL , Ael are respectively equal;* the *obtuse angled* triangles EAL and eAl , are equal; and for a like reason the triangles EAP , eAp , are equal: Again, the triangles EAG , and eAg , also EAF and eAf , having their sides respectively equal, have likewise their angles respectively equal. Now because AE and Ae are tangents, therefore $GAL = EAL - EAG$, and $gal = eAl - eAg$. Whence GAL is less than gal , by twice EAG , and for a like reason PAF is greater than pag by twice EAF .

Now while the point L of the leading palett ascends from L to G , where the tooth escapes, the corresponding point l of the other palett descends through an arch equal to GL ; but this (supposing lep a right line) is less than gl , therefore the point l in this case will not come down to g , the place of the striking tooth to receive its blow, and the tooth must *drop* until it meets the palett in some other point. To prevent this we must bring down the point l in the arch gl , to λ , making the angle $lA\lambda = \text{twice } EAG$, so that GL and $g\lambda$ may be equal, and thus the upper part of the palett will be concave. For the like reason the point p must be removed to π in the arch fp ; making $pA\pi = \text{twice } EAF$, so that PF and πf may be equal, whence the lower part of the palett will be concave. If it be intended that the retreat or recoil of the wheel on the driving palett should be exactly

the same, that of the leading palett will continually increase, but when the tooth is at E their velocities are equal, therefore the angle GAL is greater than ECG , and for the same reason the angle PAF is less than FCE , or ECG , but the whole angle described by the pendulum between beat and beat is $GAL + PAF$, half of which, or the angle through which the pendulum ascends before the wheel escapes, is therefore very nearly equal to ECG or 3 degrees.

It follows likewise that when the pendulum is at its lowest point, the tooth of the wheel will not be precisely in its mean place E , but somewhat nearer to G ; nor will the leading palett PL be then in its mean place PEL , but somewhat raised from the center C : When the pendulum is at its lowest point, the angular distance of the palett PL from the place of escapement G , is $\frac{GAL + PAF}{2}$ as was shown before, but when the palett PL is at its mean place, its angular distance from the place at which the tooth escapes is GAL , the difference of these or $\frac{GAL - PAF}{2}$ is the elevation of the palett PL above its mean place when the pendulum is at its lowest point; and the angular distance of the tooth of the wheel from its mean place E is nearly equal to it.

* Par. 189. and 192.

actly equal to the recoil on the leading palett, then the curvature of the upper part of the driving palett above λ must be further increased.

The paletts of the public clock at Trinity College *Cambridge*, set out many years ago by Mr. *John Harrison*, were made in this manner, the face of the leading palett being a plane and the face of the other palett concave, which gave rise to this enquiry. No doubt but it was done to make the force on each palett alike, and that there might be no drop, and was the result of sound reasoning, though perhaps not dressed out in all the formality of theorems and corollaries.

The following computations may assist the reader.

198. In fig. 4. let CE , the radius of the wheel, $= 10$, the angle $ACE = 45^\circ$, let AEC be a right angle, $AEL = 45^\circ$, the arches FE , EG , fe , eg , each 3 degrees, then

		Deg.	Min.	Sec.
$AC = 14,142136$	$GAL =$	3	10	31,7
$AG = 9,476665$	$PAF =$	2	51	27,6
$AF = 10,523370$	$EAG =$	0	4	58,3
$EL = 0,761758$	$EAF =$	0	4	28,6
$EP = 0,722602$	$\frac{GAL + PAF}{2} =$	3	0	59,6
$PL = 1,484360$	$\frac{GAL - PAF}{2} =$	0	9	32

$$\text{The arches } \left\{ \begin{array}{l} l\lambda = 0 \quad 9 \quad 56,6 \\ p\pi = 0 \quad 8 \quad 57,2 \end{array} \right.$$

199. The rules before laid down (par. 175.) relate only to the force of the wheel upon a given point of the palett, without enquiring into the law of that force, (that is its variation in different parts of the palett) or the effect of this variable force combined with the constant force of gravity; to which should be added the elastic force of the spring on which the pendulum hangs, the resistance of the air, and friction of the paletts, all of which affect the motion of the pendulum. Some of the principles on which such an enquiry must be founded are before laid down; but to prosecute so complicated a problem with mathematical rigour would be difficult, and perhaps at last when solved it would not be found so useful in the practical application as at first it might seem to be.

200. *Newton* says, That if the force of the wheels on the pendulum can be so compounded with that of gravity, that the whole force downwards shall be always as the length of the circular arch to be descended through and its radius directly, and as the sine of that arch inversely; then all oscillations will be isochronous.* Hence the oscillations will be isochro-

* Princip. L. 1. P. 53. Cor. 2.

isochronous, if the accelerating force along the arch be to the weight of the pendulum, as the arch to be descended through is to radius; but the accelerating force arising from gravity only is to the weight of the pendulum, as the sine of that arch to radius; therefore the additional accelerating force of the wheels should be to the weight of the pendulum, as the difference between that arch and its sine is to radius. Now it is impossible that this law should obtain intirely in any construction of paletts whatever, in part it may in some constructions. For if the additional force varies according to this law, it should be nothing at the lowest point of the arch, and increase as the arch increases both ways but in contrary directions, conspiring with the motion of the pendulum in its descent and opposing it equally in the ascent. Now in this case, the force will destroy just as much motion in the pendulum as it communicates to the pendulum, and therefore cannot preserve its vibrations: Such a force of the wheels therefore as *Newton* describes is incompatible with their office of keeping the clock in going. In the general form of paletts before considered, while the wheel moves forward, the force impressed on the palett is constantly in one direction, that in which the pendulum moves. Therefore in that part of the arch described by the pendulum which lies between the points where the wheel escapes, the force upon the paletts in no case follows the law specified: In the dead beat, at the extremities this force is nothing, where according to this law it ought to be greatest: In the recoiling paletts indeed, during the recoil, this force conspires with and opposes the motion of the pendulum agreeably to the general nature of the law before mentioned, but not in the specific degree required; however this circumstance in concurrence with others, has I suppose induced Mr. *Harrison* to prefer a considerable recoil to the dead beat.

201. The common form of paletts before considered is by no means the only one; there are many others to be met with in *Thiout*, *Le Paute*, and other writers: nor ought that to be overlooked which Mr. *Harrison* has made use of in his three great machines; the nature of which is represented in figure 5. In this, C is the center of the wheel, A the center of the verge, A F represents part of the fork, or it may represent one of the radii of the balance; P I is the hook or moveable part of the palett, turning on a joint I at the end of an arm I A coming out from the verge. The tooth E of the wheel lays hold of the inside of the hook, and carries the whole away with it, and consequently gives the arm I A, and the whole verge, a circular motion round its center A. It should be observed, that in the time of action, the point of the tooth does not slide at all, or change its place on the face of the hook; but the tooth and hook have relatively to each

each other a very small circular motion round the point of contact. The hook P I is disengaged from the tooth E by the hook of the other pallet when it encounters the opposite tooth of the wheel; the manner of which we need not here consider.

202. The method of computing the force of the wheel upon pallets of this sort is exceedingly simple. For through the center I on which the hook turns, and the point E of the tooth that seizes it, draw an indefinite right line S L, on this, from C and A, (the centers of the wheel and verge) let fall the perpendiculars C L, A S, and the force upon the wheel is to that upon the verge when these forces (applied as before mentioned, par. 176,) balance each other, as C L to A S. This is so evident it needs no formal demonstration.* — What may be effected in this construction of pallets by a judicious disposition of the several centers, is left for the reader's consideration.

203. From what has been said, it seems in vain to expect that the vibrations of a pendulum can be rendered perfectly isochronous by any contrivance in the pallets only. It was for this reason, I suppose, that Mr. *Harrison* in his third machine, applied a piece of mechanism, which he called a *saddle piece*, purposely calculated to correct the error of the larger vibrations arising from the defective law of the force upon the balance. In this the additional force at the point of rest was, I believe, nothing, and increased both ways as before mentioned; at least the machinery was capable of giving the additional force this or any other law at pleasure; nor did it fail through any defect in the contrivance, but because the true nature of the correction to be made was mistaken; Mr. *Harrison* at that time supposing the motion of the balance to be perfectly analogous to that of the pendulum, as had been generally held: and though this attempt succeeded not, because founded upon a false principle, yet it was the means of discovering the true one.

204. Besides what has been mentioned, there is another contrivance for this purpose, first introduced by *Huygens*, namely cycloidal cheeks; which I believe have been laid aside too hastily. The cheeks originally designed by *Huygens*† are indeed much too weak when the pendulum is hung upon a

* These pallets are mentioned by Mr. *Cumming* in his Essay on Clock-work, par. 226, where he says, that “Mr. *Harrison* informed him, that the action of the wheel on the pendulum was the same with the action of gravity thereon.” In this he has grossly misunderstood Mr. *Harrison*, who knew perfectly well how to calculate the action of the wheel on the pendulum, communicated by means of the pallets he had invented; and any one else who had seen both these pallets and others on the same principle by Mr. *Hindley* would have known the rule too, had he been acquainted with the first elements of mechanics.

† Horolog. oscillator. pars prima.

a watch spring as is now the universal practice; such cheeks will undoubtedly bend and change their form by the force of the spring: But in *Huygens'* original design, the pendulum was suspended by two silk lines, (which is the practice of the *French* in their table clocks to this day;) and in that case such cheeks may be strong enough. *Huygens* further directs them to be made perfect cycloids; but this is founded on a theory manifestly defective, as it takes no account of the variation of the force upon the pendulum from the form of the paletts, elasticity of the spring, resistance, friction, and perhaps other causes. In such a complicated case as this, the form of the cheeks should be determined, not *mathematically* but *experimentally*; they should be so constructed that their curvature may be increased or diminished as the case on repeated trials shall be found to require.

205. Mr. *Harrison* has constructed cheeks of this kind in a form that renders them exceedingly strong, and yet their curvature can be altered at pleasure by screws made for that purpose. The whole was intended to be fixed to the wall of the house, and has a contrivance to find its proper place, so as to correspond truly to the work of the clock. *

206. How far these inventions may improve clocks remains to be tried. In the mean time, if the pendulum be properly suspended, and its length not subject to be changed by the weather; a clock of the common construction with dead seconds will go well enough for any astronomical purposes whatever. From the account given in par. 5. it appears that the observatory clock could always be depended on for ten days or a fortnight, so as not to gain or lose in that time above a second or two at the most, more than what was to be expected from its precedent rate of going; an astronomer must have bad luck indeed, if in that time he cannot take a observation either of the sun or stars by which he may examine the going of his clock, and determine its error.

* Mr. *Harrison* seems to be the first who both in conversation and in print, (*Philos. Trans.* Vol. XLVII. p. 517.) insisted so much on the importance of a very firm suspension of the pendulum: And it appears both from theory and experience to be of more consequence than all the contrivances of cheeks, paletts, and saddles put together. From him some others have gleaned it up. Mr. *Cumming* recommends the suspending of the pendulum upon a block of marble of 4 or 500 pounds weight laid into the wall, which indeed is the best piece of advice in his book.

A P P E N D I X.

The subjects of the following papers have so near a relation to what has been treated of before, that it seems not improper to subjoin them.

Observations made at Cambridge on the transit of Venus over the Sun in 1761.

ABOUT the beginning of *May* 1761, a clock was set up in the turret, now made a part of the observatory at *St. John's College*; the pendulum, whose rod was iron, was suspended upon an iron cock, strongly fixed to the wall. This clock was compared with a regulator belonging to *Dr. Mason* of *Trinity College*; the bell of the college clock serving as a common signal for marking the time shown by each of the other two clocks. *Dr. Mason's* regulator was examined by a transit telescope fixed in his own room, and which was at that time the only transit instrument in *Cambridge*.* The observations for examining the clocks were as follows :

Day of the month 1761.	Passage of the Sun over the meridian by <i>Dr. Mason's</i> regulator.						Comparison of the two clocks.	
	West. limb.			East. limb.			Days of Comparison.	Clock at <i>St. John's</i> faster than regulator.
	H.	M.	S.	H.	M.	S.		
May 25	XI	56	6	XI	58	22	May 25 at XII	M. S. 0 11
30	XI	56	46	XI	59	3	30 at XII	1 22
June 6	XI	57	57	XII	0	14½	June 6 at IX	3 14
							6 at XII	3 14

Hence we may conclude that at the time of the transit of the planet, *Dr. Mason's* regulator was 54 seconds slower, and the clock at *St. John's College* 2' 20" faster than apparent time.

Two observers upon the leads at *St. John's College* attended the transit, while another person counted the clock. One of these observers had a reflecting telescope made by *Mr. Short*, of 9,6 inches focal distance, which magnified 38 times; the other had a refracting telescope made by *Mr. Dollond* with a compound object-glass of $66\frac{2}{3}$ inches focal length, and a single eye-glass of one inch focal length. Both observers agreed to a second in noting the time of the internal contact, but differed somewhat in

* This transit telescope was 3 feet long, and magnified about 18 times; it had been frequently and carefully rectified to the meridian.

in that of the external contact, and more in noting the time of the bisection of the planet by the limb of the sun, which indeed was estimated by the eye only. Their observations were as follows. The internal contact at $\text{VIII}^{\text{h}} 21' 29''$, the bisection at $\left\{ \begin{array}{l} \text{VIII}^{\text{h}} 29' 40'' \\ \text{VIII}^{\text{h}} 30' 38'' \end{array} \right.$ the last contact at $\left\{ \begin{array}{l} \text{VIII}^{\text{h}} 38' 56'' \\ \text{VIII}^{\text{h}} 39' 4'' \end{array} \right.$ according to the time shown by the clock at St. John's College.

Dr. *Mason* observed the transit at his own room with a refracting telescope. The internal contact seemed to him to continue for five or six seconds of time, it being so long before the planet broke through the sun's limb. The middle of the internal contact was at $\text{VIII}^{\text{h}} 18' 14''$, the last contact at $\text{VIII}^{\text{h}} 36' 18''$, according to the time shown by his regulator.

These observations reduced to apparent time, give the internal contact as observed at St. John's College, at $\text{VIII}^{\text{h}} 19' 9''$, the last contact at $\text{VIII}^{\text{h}} 36' 44''$. The duration $17' 35''$. The internal contact as observed by Dr. *Mason* at $\text{VIII}^{\text{h}} 19' 8''$, the last contact at $\text{VIII}^{\text{h}} 37' 12''$, the duration $18' 4''$.

*Two papers relating to Mr. Harrison's discoveries, given in to the Board of Longitude.**

A short View of the Improvements made or attempted in Mr. Harrison's Watch.

THE defects in common watches, which Mr. *Harrison* proposes to remedy, are chiefly these:

1. That the main spring acts not constantly with the same force upon the wheels, and through them upon the balance;
2. That the balance, either urged with an unequal force, or meeting with a different resistance, from the air, or the oil, or the friction, vibrates through a greater or less arch;
3. That these unequal vibrations are not performed in equal times;
4. That the force of the balance spring is altered by a change of heat.

1. To remedy the first defect, Mr. *Harrison* has contrived, that his watch shall be moved by a very tender spring, which never unrolls itself more than one eighth part of a turn, and acts upon the balance through one wheel only. But such a spring cannot keep the watch in motion a long

* I do not recollect the exact date of this paper, but it was sometime in September 1765, when another on the same subject was sent to the Board by Mr. *M*.

long time. He has therefore joined another, whose office is to wind up the first spring eight times in every minute, and which is itself wound up but once in a day.

2. To remedy the second defect, Mr. *Harrison* uses a much stronger balance spring, than in a common watch. For if the force of this spring upon the balance remains the same, whilst the force of the other varies, the errors arising from that variation will be the less, as the fixed force is the greater. But a stronger spring will require either a heavier or a larger balance. A heavier balance would have a greater friction. Mr. *Harrison* therefore increases the diameter of it. In a common watch it is under an inch, in this of Mr. *Harrison's*, two inches and two tenths.

3. Had these remedies been perfect, it would have been unnecessary to consider the defects of the third sort. But the methods already described, only lessening the errors, not removing them, Mr. *Harrison* uses two ways to make the times of the vibrations equal, though the arches may be unequal. One is to place a pin, so that the balance spring, pressing against it, has its force increased; but increased less when the vibrations are larger: the other to give the paletts such a shape, that the wheels press them with less advantage, when the vibrations are larger.

4. To remedy the last defect, Mr. *Harrison* uses a bar compounded of two thin plates of brass and steel, about two inches in length, rivetted in several places together, fastened at one end, and having two pins at the other, between which the balance spring passes. If this bar be straight in temperate weather (brass changing its length by heat more than steel) the brass side becomes convex when it is heated; and the steel side, when it is cold: And thus the pins lay hold of a different part of the spring in different degrees of heat, and lengthen or shorten it, as the regulator does in a common watch.

The two first of these improvements any good workman, who should be permitted to view and take to pieces Mr. *Harrison's* watch, and be acquainted with the tools he uses, and the directions he has given, could without doubt exactly imitate. He could also make the paletts of the shape proposed; but for the other improvements, Mr. *Harrison* has given no rules. He says that he adjusted those parts by repeated trials, and that he knows no other method. This seems to require patience and perseverance; but with these qualifications other workmen need not despair of success equal to Mr. *Harrison's*. There is no reason to suspect that Mr. *Harrison* has concealed from us any part of his art.

If our opinion of the excellence and usefulness of this machine be asked, I must fairly own, that nothing but experience can determine the

value of it with certainty; however, I think it my duty to declare to the Board the best judgment I can form.

The first of Mr. *Harrison's* alterations is, I believe, an improvement, but not very considerable. Probably if the other defects in common watches could be removed, the changes in the force of the main spring would not occasion such errors, as would make them useless at sea.

The next alteration seems to be of greater importance. I suppose that it contributes more to the exactness of the watch, than all the other changes put together. But it is attended with some inconvenience. The watch is liable to be disordered, and even stopt by almost any sudden motion, and when stopt does not move again of itself. But as it has gone two voyages without any such accident, it may seem, that this danger at sea, is not considerable.

The principle on which Mr. *Harrison* forms the alterations of the third sort, is, that the longer vibrations of a balance moved by the same spring are performed in less time. This is contrary to the received opinion among philosophers and workmen. But if Mr. *Harrison* be right, yet whether the method he has proposed, will correct the errors or not, is to me quite uncertain.

The last alteration beforementioned, is ingenious and useful; but that it can be made to answer exactly to the different degrees of heat, seems not probable.

*A Memorial presented to the Honourable the Commissioners of the Board of Longitude.**

THE persons appointed to receive Mr. *Harrison's* discovery were desirous, at their first meeting, when the business of the day was over, to take the drawings and description away with them; that they might the better recollect what Mr. *Harrison* had delivered, and be prepared for the next day's explanation. This Mr. *Harrison* refused, and therefore at the subsequent meetings, every one took what notes he thought proper, to assist his own memory. Many of these were measures of parts expressed in the drawings now to be published; others short descriptions of some parts whose construction seemed difficult to be remembered, frequently in Mr. *Harrison's* own expressions, and such as are not commonly used by other workmen. Some indeed were set down by common consent, and were intended as additions to the measures given in the margin of his drawings. These are subjoined below; but for the rest, Mr. *Ludlam* hopes the Board will not print in his name

* I have forgot the precise date of this paper, but it was sent a little before the publication of the Principles of Mr. *Harrison's* Time-keeper, to which it relates.

a few hasty memorandums, which he always thought much too trifling to be offered to them or the public.

	Penny wt.	Grains.
Weight of the balance rim with its 3 bars	0	$28\frac{3}{8}$
balance wheel with its pinion and arbor	0	8
contrate wheel, with that carrying the seconds	0	$37\frac{1}{2}$
main spring	23	18
second spring	2	8
third spring	0	$3\frac{1}{2}$
Length of the main spring	60	Inches.
second spring	16	
third spring	10	

The main spring is poised at the fusee in the usual manner, by a weight of 3 oz. *Troy*, at the distance of 7,2 inches.

The third spring (when at the mean state of force with which it acts on the contrate wheel) is poised by a weight of 43 grains *Troy* hung on the rim of the contrate wheel.

The following theorem relating to the motion of a balance may serve to explain some passages in Mr. Harrison's paper.

Let a balance be made to vibrate by the force of a spiral spring acting at right angles to one of its radii, at a given distance from the center. Let the force of the spring be as its compression or expansion; and let us neglect all the other matter in the balance, and consider only that which is contained in the rim. Let T be the time of one vibration, R the radius of the balance, P its weight, F the absolute force of the spring at a given tension; then will TT be as $\frac{RRP}{F}$.

Mathematicians will easily deduce this from the fundamental laws of motion. *

Cor. 1. Hence the force of the balance spring (the time of one vibration and weight of the balance being the same) is as the square of the diameter of the balance.

Cor. 2. The strength of the balance spring (the diameter and weight of the balance being the same) is inversely as the square of the time of one vibration.

Cor. 3. The weight of the balance (the strength of the spring and time of a vibration being the same) is inversely as the square of its diameter; therefore a large balance vibrating in the same time with the same spring, will be much lighter than a small one. Hence likewise, if a balance be made with two balls joined by a rod, (as in Mr. *Harrison's* first and

* It follows immediately from the 38 prop. of the first book of *Newton's Principia*.

and second machines,) if the weights and distances of these balls from their common center of motion be unequal, but such that each separately would vibrate in the same time; then the center of gravity of these balls will not fall on their center of motion, nor will they poise each other: for to make this equilibrium, P should be inversely as R, whereas if each vibrates in the same time, P must be inversely as R R.

Lastly, If we suppose the rim of the balance to be always of one breadth and thickness, so that P shall be as R, then T T is as $\frac{R^3}{F}$, and the strength of the spring must be as the cube of the diameter of the balance, that the time of a vibration may be the same.

These conclusions, among many others, Mr. *Harrison* investigated (in all probability) by strength of parts only, without any assistance from men or books; and as they are not to be found in the common tracts of philosophy, I thought it not improper to put them down here.

An account of the going of a Clock with a wooden Pendulum,
Communicated by a Gentleman in *London*.
It was observed by a Transit Instrument.

	Seconds per diem.	Heat at a medium.		Seconds per diem.	Heat at a medium.
1766.	<i>Loft.</i>		1767.	<i>Loft.</i>	
From Mar. 3. to Mar. 28.	0,13		Apr. 9. to Apr. 27.	1,0	53
Mar. 28. to May 6.	0,15				
May 6. to June 2.	0,78	57	<i>The pendulum altered.</i>		
June 2. to July 8.	1	61			
July 7. to Aug. 1.	1,35	66	1767.		
Aug. 10. to Aug. 20.	1,26	67	From Oct. 9. to Oct. 14.	0,2	52
Aug. 20. to Sept. 25.	0,56		Oct. 14. to Oct. 30.	0,7	58
Sept. 25. to Oct. 3.	0,94	66	Oct. 30. to Nov. 13.	2,2	56
	<i>Got.</i>		Nov. 13. to Dec. 1.	1,5	50
Oct. 3. to Oct. 13.	0,05	59	Dec. 1. to Dec. 22.	2,0	51
Oct. 13. to Oct. 31.	0,03	55	Dec. 22. to Jan. 26.	0,9	38
	<i>Loft.</i>		1768.		
Oct. 31. to Nov. 6.	1,4	55	Jan. 26. to Feb. 2.	1,6	53
Nov. 6. to Nov. 13.	0,5	51	Feb. 2. to Mar. 4.	1	49
Nov. 13. to Nov. 22.	0,4	55	Mar. 4. to Mar. 23.	0,1	48
Nov. 22. to Nov. 28.	1,0	49		<i>Got.</i>	
Nov. 28. to Dec. 2.	1,0	49	Mar. 23. to Apr. 3.	1,4	50
Dec. 2. to Dec. 14.	0,98	48	Apr. 3. to Apr. 11.	1,7	55
Dec. 14. to Dec. 19.	0,6	47	Apr. 11. to Apr. 20.	2,2	58
1767.			Apr. 20. to Apr. 28.	3	57
Dec. 19. to Jan. 2.	0,6	47	Apr. 28. to May 8.	2,6	63
	<i>Got.</i>		May 8. to May 18.	2,5	62
Jan. 2. to Jan. 30.	0,2	39	May 18. to May 31.	3,2	61
	<i>Loft.</i>		May 31. to June 9.	2	68
Jan. 31. to Feb. 21.	0,2	49	June 9. to June 21.	2,2	60
Feb. 21. to Mar. 3.	1,4	46	June 21. to July 1.	1	64
Mar. 3. to Mar. 8.	1,7	49	July 1. to July 12.	0,1	68
Mar. 8. to Mar. 20.	1	47	July 12. to July 19.	0,6	65
Mar. 20. to April 4.	1,9	53	July 19. to July 23.	0,7	68
Apr. 4. to Apr. 9.	2,0	59	July 23. to Aug. 12.	0,6	69

T H E E N D.

The following useful Tables were communicated, by the Right Honourable the Lord CHARLES CAVENDISH, after the foregoing Sheets were printed off.

Difference to be subtracted from Sidereal Time to reduce it to Mean Time.

H.	'	"	'	"	'	"
1		9,830	1	0,164	30	4,915
2		19,659	2	0,328	31	5,077
3		29,488	3	0,491	32	5,242
4		39,318	4	0,655	33	5,406
5		49,147	5	0,819	34	5,570
6		58,977	6	0,983	35	5,734
7	1	8,806	7	1,147	36	5,898
8	1	18,636	8	1,311	37	6,061
9	1	28,466	9	1,474	38	6,225
10	1	38,296	10	1,638	39	6,389
11	1	48,125	11	1,802	40	6,553
12	1	57,955	12	1,966	41	6,717
13	2	7,784	13	2,129	42	6,881
14	2	17,614	14	2,293	43	7,044
15	2	27,443	15	2,457	44	7,208
16	2	37,273	16	2,621	45	7,372
17	2	47,102	17	2,785	46	7,536
18	2	56,932	18	2,949	47	7,700
19	3	6,761	19	3,112	48	7,863
20	3	16,591	20	3,276	49	8,027
21	3	26,420	21	3,440	50	8,191
22	3	36,250	22	3,604	51	8,355
23	3	46,080	23	3,768	52	8,519
24	3	55,909	24	3,932	53	8,681
			25	4,095	54	8,846
			26	4,259	55	9,010
			27	4,423	56	9,174
			28	4,587	57	9,338
			29	4,751	58	9,502
			30	4,915	59	9,665
					60	9,829

Error of a Transit Instrument in Seconds of Time for different Declinations when the Instrument is right in all respects, except that mentioned at the Head of each Table. The Error is marked + when the Observation, by the Instrument, happens sooner than it ought to do, the Error being in that case to be added to the Time observed. Those marked * are for the Lower Meridian, or under the Pole. Latitude $51^{\circ} 31'$.

Declination.	When East End of Axis is depressed $\frac{1}{4}$ Minute.	When the Telescope is directed to a Point $\frac{1}{4}$ Minute distant from the South towards the East.	Time of $\frac{1}{4}$ Minute passing Meridian.	When the Telescope points $\frac{1}{4}$ Minute too near to the East End of Horizontal Axis.	
				And is set to South Point of Horizon.	And is set to North Point of Horizon.
35 South	+ 0,07 Sec.	+ 1,22 Seconds.	1,22 Seconds.	+ 0,00 Seconds.	+ 2,44 Seconds.
30	+ 0,17	+ 1,14	1,15	+ 0,01	+ 2,29
25	+ 0,25	+ 1,07	1,10	+ 0,03	+ 2,17
20	+ 0,33	+ 1,01	1,06	+ 0,05	+ 2,07
15	+ 0,41	+ 0,95	1,04	+ 0,09	+ 1,99
10	+ 0,48	+ 0,89	1,02	+ 0,13	+ 1,91
5	+ 0,55	+ 0,84	1,00	+ 0,16	+ 1,84
0	+ 0,62	+ 0,78	1,00	+ 0,22	+ 1,78
5 North	+ 0,69	+ 0,73	1,00	+ 0,27	+ 1,73
10	+ 0,76	+ 0,67	1,02	+ 0,35	+ 1,69
15	+ 0,83	+ 0,62	1,04	+ 0,42	+ 1,66
20	+ 0,91	+ 0,56	1,06	+ 0,50	+ 1,62
25	+ 0,99	+ 0,49	1,10	+ 0,61	+ 1,59
30	+ 1,07	+ 0,42	1,15	+ 0,73	+ 1,57
35	+ 1,17	+ 0,35	1,22	+ 0,87	+ 1,57
40	{ + 1,28 - 0,04 *	+ 0,26 + 1,30 *	1,31	+ 1,05 - 2,61 *	+ 1,57 - 0,01 *
45	{ + 1,40 - 0,17 *	+ 0,16 + 1,40 *	1,41	+ 1,25 - 2,81 *	+ 1,57 - 0,01 *
50	{ + 1,55 - 0,32 *	+ 0,04 + 1,52 *	1,56	+ 1,52 - 3,08 *	+ 1,60 - 0,04 *
55	{ + 1,74 - 0,50 *	- 0,11 + 1,67 *	1,74	+ 1,85 - 3,41 *	+ 1,63 - 0,07 *
60	{ + 1,97 - 0,73 *	- 0,30 + 1,86 *	2,00	+ 2,30 - 3,86 *	+ 1,70 - 0,14 *

Error

Error of a Transit Instrument, &c.

Declina- tion.	When East End of Axis is de- pressed $\frac{1}{4}$ Mi- nute.	When the Tele- scope is direct- ed to a Point $\frac{1}{4}$ Minute di- stant from the South towards the East.	Time of $\frac{1}{4}$ Mi- nute passing the Meridian.	When the Telescope points $\frac{1}{4}$ Minute too near to the East End of Horizontal Axis.	
				And is set to South Point of Horizon.	And is set to North Point of Horizon.
65 North	{ + 2,30 Sec. — 1,07 *	— 0,55 Sec. + 2,12 *	2,37 Sec.	+ 2,92 — 4,49 *	+ 1,82 Sec. — 0,25 *
70	{ + 2,77 — 1,53 *	— 0,93 + 2,49 *	2,92	+ 3,85 — 5,41 *	+ 1,99 — 0,43 *
75	{ + 3,53 — 2,30 *	— 1,54 + 3,10 *	3,86	+ 5,40 — 6,96 *	+ 2,32 — 0,76 *
80	{ + 5,05 — 3,82 *	— 2,75 + 4,31 *	5,76	+ 8,51 — 10,07 *	+ 3,01 — 1,45 *
85	{ + 9,57 — 8,33 *	— 6,33 + 7,90 *	11,47	+ 17,80 — 19,37 *	+ 5,14 — 3,57 *
88 3' 54"	{ + 24,45 — 23,22 *	— 17,63 + 19,20 *	29,62	+ 47,25 — 48,82 *	+ 11,99 — 10,42 *

Error of the Time of a Star's passing from the Upper Meridian to the Lower, which is marked + when the Time is greater than 12 Hours Sidereal Time.

40	+ 1,31 Sec.	— 1,04 Sec.	+ 3,66 Sec.	+ 1,58 Sec.
45	+ 1,57	— 1,24	+ 4,06	+ 1,58
50	+ 1,87	— 1,48	+ 4,60	+ 1,64
55	+ 2,23	— 1,78	+ 5,26	+ 1,70
60	+ 2,70	— 2,16	+ 6,16	+ 1,84
65	+ 3,37	— 2,67	+ 7,41	+ 2,07
70	+ 4,30	— 3,42	+ 9,26	+ 2,42
75	+ 5,83	— 4,64	+ 2,36	+ 3,08
80	+ 8,87	— 7,06	+ 18,58	+ 4,46
85	+ 17,90	— 14,23	+ 37,17	+ 8,71
88 3' 54"	+ 47,67	— 36,83	+ 96,07	+ 22,41

Correction

Correction for the Time of Noon found by equal Altitudes of the Sun for every six Degrees of Longitude. For the Latitude of $51^{\circ} 31'$.

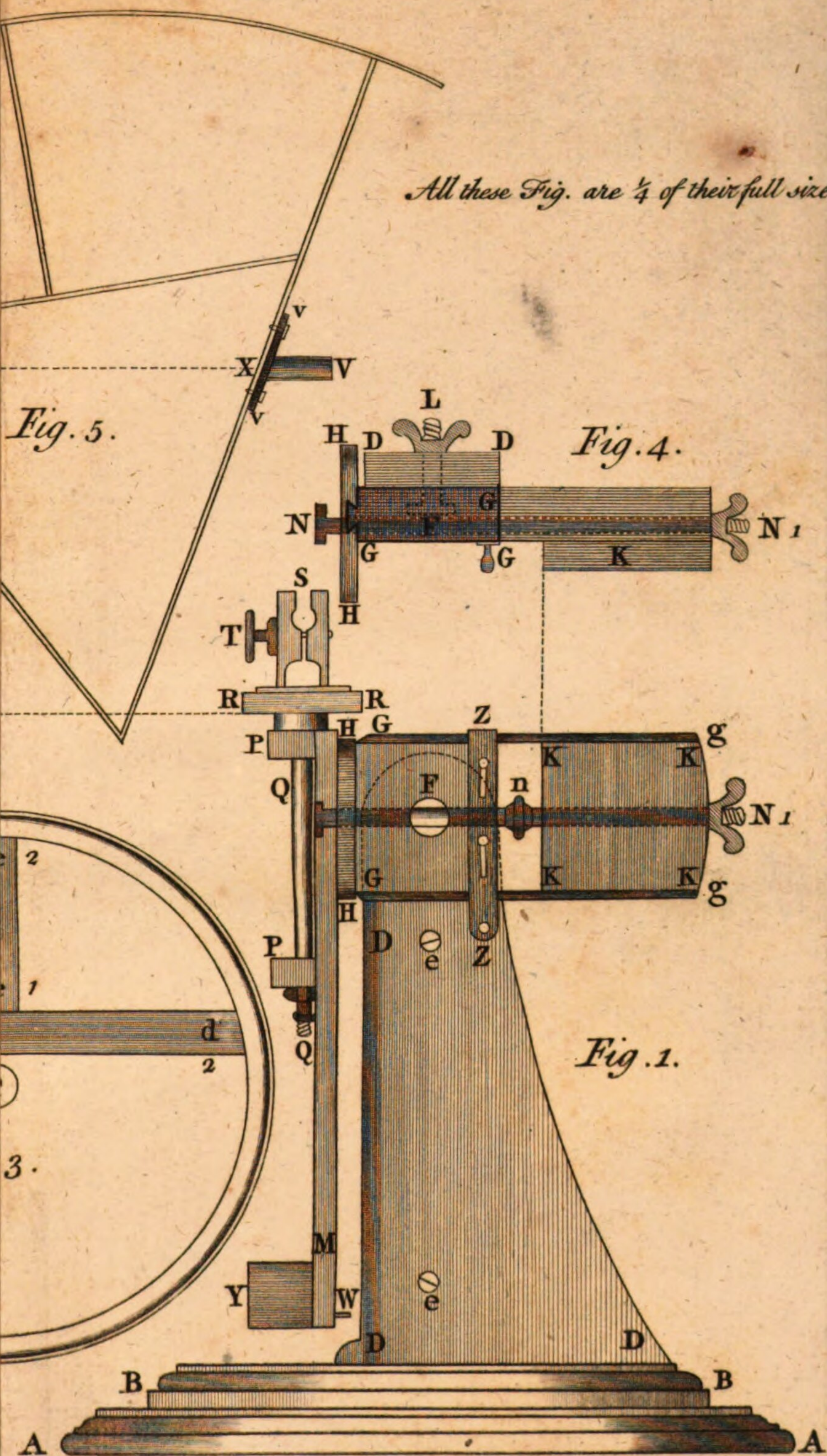
To be added in descending Signs, and subtracted in ascending Signs.

Sun's Long.		Dec.	Interval of Observations in Hours.										Sun's Long.		A.
			12 H.	11 H.	10 H.	9 H.	8 H.	7 H.	6 H.	5 H.	4 H.	3 H.			
S	D	° ' "	"	"	"	"	"	"	"	"	"	"	S	D	
III.	6	23 20	3,26	2,88	2,50	2,30	2,08	1,90	1,75	1,63	1,53	1,46	24	1,001	
	12	22 56	6,47	5,72	5,10	4,58	4,14	3,78	3,49	3,25	3,06	2,91	18	1,002	
	18	22 16	9,58	8,48	7,57	6,81	6,17	5,65	5,21	4,86	4,58	4,38	12	1,003	
	24	21 20	12,53	11,11	9,94	8,96	8,15	7,47	6,91	6,46	6,11	5,84	6	1,004	
IV.	0	20 11	15,30	13,61	12,20	11,03	10,06	9,25	8,58	8,05	7,62	7,30	II.	0	1,005
	6	18 48	17,8	15,93	14,34	13,00	11,89	10,97	10,22	9,61	9,12	8,75	24	1,006	
	12	17 13	20,19	18,06	16,31	14,85	13,62	12,62	11,79	11,12	10,59	10,19	18	1,007	
	18	15 27	22,25	19,98	18,11	16,55	15,24	14,17	13,29	12,58	12,01	11,59	12	1,008	
	24	13 32	24,07	21,69	19,73	18,11	16,75	15,63	14,72	13,97	13,38	12,94	6	1,009	
V.	0	11 29	25,64	23,21	21,20	19,53	18,14	17,00	16,06	15,30	14,70	14,25	I.	0	1,009
	6	9 19	26,92	24,47	22,44	20,77	19,37	18,23	17,28	16,52	15,92	15,47	24	1,010	
	12	7 4	27,96	25,52	23,51	21,84	20,46	19,32	18,35	17,64	17,05	16,60	18	1,010	
	18	4 45	28,74	26,34	24,37	22,75	21,39	20,28	19,37	18,64	18,07	17,63	12	1,010	
	24	2 23	29,21	26,88	24,99	23,42	22,11	21,04	20,17	19,47	18,91	18,50	6	1,010	
VI.	0	0 0	29,55	27,31	25,49	23,99	22,74	21,72	20,89	20,23	19,70	19,30	O	0	1,011
	6	2 23		27,31	25,60	24,19	23,02	22,06	21,29	20,67	20,17	19,81	24	1,010	
	12	4 45		27,16	25,57	24,25	23,17	22,28	21,40	20,99	20,54	20,19	18	1,010	
	18	7 4			25,25	24,04	23,05	22,24	21,58	21,06	20,65	20,34	12	1,010	
	24	9 19			24,67	23,58	22,68	21,95	21,36	20,90	20,53	20,25	6	1,010	
VII.	0	11 29			23,83	22,85	22,05	21,41	20,89	20,47	20,15	19,90	XI.	0	1,008
	6	13 32				21,81	21,11	20,54	20,10	19,73	19,45	19,21	24	1,008	
	12	15 27				20,48	19,88	19,40	19,01	18,71	18,47	18,29	18	1,008	
	18	17 13					18,34	17,93	17,61	17,35	17,16	17,01	12	1,007	
	24	18 48					16,47	16,14	15,88	15,67	15,51	15,39	6	1,006	
VIII.	0	20 11					14,30	14,04	14,02	13,67	13,54	13,45	X.	0	1,006
	6	21 20					11,84	11,64	11,48	11,36	11,26	11,19	24	1,004	
	12	22 16						8,99	8,84	8,79	8,72	8,67	18	1,003	
	18	22 56						6,12	6,05	5,99	5,95	5,92	12	1,002	
	24	23 20						3,10	3,06	3,03	3,01	3,00	6	1,001	
IX.	0	23 28						0,00	0,00	0,00	0,00	0,00	IX.	0	

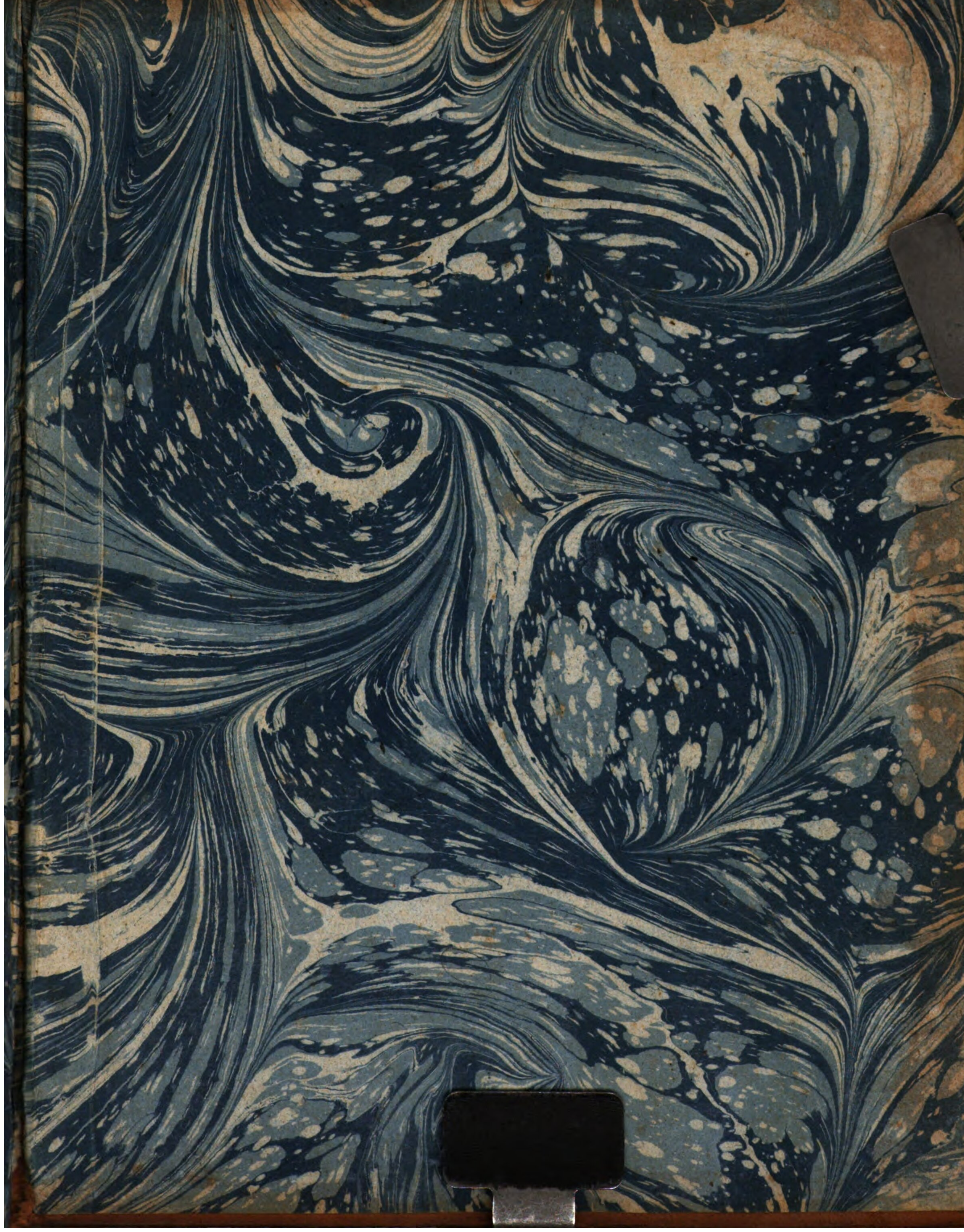
To make this Correction serve for the ascending Signs, each of the Numbers in the Table is to be multiplied by the corresponding Number in Column A; and is to be subtracted from the Time of Noon found by equal Altitudes.

T H E E N D.

All these Fig. are $\frac{1}{4}$ of their full size







Ludlam, William,

Astronomical Observations made in St. John's College, Cambridge, in the
years 1767 and 1768

Cambridge 1769

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